UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
ENTOMOLOGY RESEARCH DIVISION
Beltsville, Maryland 20705

Proceedings of Planning and Training Conference for Insect Population Suppression

Holiday Inn
Memphis, Tennessee
April 26-28, 1965

FOR ADMINISTRATIVE USE ONLY

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
ENTOMOLOGY RESEARCH DIVISION
Beltsville, Maryland 20705

March 30, 1965

To: All Conference Participants

From: E. F. Knipling, Director, Entomology Research Division

Subject: Planning and Training Conference April 26-28, 1965, at the Holiday Inn West, 980 South 3rd Street, Memphis, Tennessee

We are pleased to advise you that a planning and training conference on the subject Insect Population Suppression will be held at the Holiday Inn, Memphis, Tennessee, April 26-28, 1965. A copy of the agenda is enclosed for your information. The program and plans for the conference were developed by a committee consisting of L. D. Christenson, Chairman, P. Luginbill, D. F. Martin and R. R. Rhodes.

Our purpose at this conference will be to exchange information and discuss plans for further work in this interesting and timely phase of research. You will note that emphasis will be placed on the use of various methods that might be employed to suppress total insect populations.

Speakers assigned special topics will be expected to submit resumes, not to exceed one typewritten page, of their talks prior to or immediately after the close of the conference. We wish to encourage short reports of work done by others, even though not listed in the program. Questions and discussions by all those in attendance are encouraged. Brief summaries of remarks volunteered from the floor may also be submitted for inclusion in the final report of the conference.

If you have questions regarding the conference and your participation in the discussions, these should be referred to your Branch Chief.

E. F. Knipling

Enclosure

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
ENTOMOLOGY RESEARCH DIVISION
Beltsville, Maryland 20705

March 29, 1965

PLANNING AND TRAINING CONFERENCE on INSECT POPULATION SUPPRESSION

Holiday Inn
Memphis, Tennessee
April 26-28, 1965

PROGRAM

Monday, April 26 — Page No.

ROLE OF ATTRACTANTS AS APPLIED TO POPULATION SUPPRESSION
(E. A. Taylor, Discussion Leader)

Light, Infrared, and Other Physical Attractants

5:00 p.m. - - Adjournment

Tuesday, April 27

8:00 a.m. -- ROLE OR POTENTIAL ROLE OF ATTRACTANTS IN POPULATION SUPPRESSION
(E. A. Taylor, Discussion Leader)

Sex Attractants

BIOLOGICAL CONTROL AS APPLIED TO SUPPRESSION OF INSECT POPULATIONS
(F. R. Lawson, Discussion Leader)

Mass Rearing and Distribution of Parasites, Predators and Diseases

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Principles of Insect Population Control

E. F. Knipling, Director
Entomology Research Division
Beltsville, Maryland

The purpose of this Planning and Training Conference is to consider insect population suppression. I am convinced that we must have a better understanding of the fundamentals of insect population control if we are to take full advantage of some of the methods of insect control now being emphasized in the Division's research program. Some of the methods will be feasible and practical only when applied against the total population or against large segments of the population. They have great potential for meeting certain insect problems when properly integrated with other systems of insect control. Their greatest value fortunately should be against some of our most important pests which cause high losses and which now necessitate costly and often objectionable control procedures.

Outstanding progress is being made in the use of insect attractants, in the use of the sterile insect release method, as well as in other more conventional ways to suppress insect populations. However, we have much to learn about insect population behavior and how to integrate various control methods effectively. Different methods of control affect insect populations in different ways, but each insect population has its distinctive feature that must be considered in considering the merits and limitations of different control methods. We should consider the basic trends of insect populations when subjected to different methods of control. To do this we should first consider a model showing the characteristic trend of an uncontrolled insect population starting from a low level. This is shown in Model 1, below.

Model 1.--Characteristic trend of an uncontrolled population.

Generation	Number of insects (5x Increase rate per generation)
Parent	1,000,000
F_1	5,000,000
F_2	25,000,000
F_3	125,000,000

I have assumed that the population of many insect species normally increases at a 5 fold rate per generation until the maximum density for the particular environment is reached. I know the rate of increase and maximum density level will vary with the species and with the circumstances. A higher rate can be expected for many insects under favorable conditions. However, it is apparent that to reverse an upward trend of a population it is necessary to achieve relatively high rates of kill. In the above model it would be necessary to kill 80% of the population of each generation to prevent an increase.

A high kill of insects in a population by the use of insecticides each generation will greatly affect population trends, but it is difficult to achieve theoretical zero without extensive use of insecticides. We know this from experience.

Model 2 shows the trend of an insect population subjected to 98% kill of the insects each generation.

Model 2.--Characteristic trend of a population treated with insecticides which produces 98% kill each generation. The model projects a 5 fold increase for survivors.

Generation	Number of insects	
	Before treatment	After treatment
Parent	1,000,000	20,000
F_1	100,000	2,000
F_2	10,000	200
F_3	1,000	20
F_4	100	2
F_5	10	<1

There are several features about this model that should be noted. It would be necessary to apply insecticides to a population for 6 generations to achieve theoretical elimination of a starting population of 1,000,000 insects, even when the rate of kill is high. It should be kept in mind that several treatments may be required per generation to achieve 98% kill for one generation. Thus, the total number of applications involved may far exceed the total number of generations requiring treatment. The insecticide treatment method is nevertheless highly efficient when the population is high. Treatments the first generation would kill 980,000 insects. As the population diminishes each treatment has the same percentage effect, but each treatment becomes less and less efficient in terms of numbers of insects killed. Theoretically, it takes just as many treatments and as much insecticide to kill 98 of 100 insects as to kill 980,000 of 1 million insects.

In contrast with conventional chemical control, other systems of insect population control have different effects on population trends. The sterile insect release method is highly inefficient when the natural population is high but highly efficient when low. Note in Model 3 the requirements for eliminating a population consisting of 1,000,000 insects when the initial release rate is 50 sterile to 1 fertile. This ratio would be required to achieve the same effect as 98% control by destruction. It would take 101,000,000 sterile insects to achieve elimination of the population. If the population of 1,000,000 represented a high population per unit area, the use of the sterile insect release method would probably be impractical. However, if it represented a low population per unit

area the use of 100 million sterile insects might be the most practical procedure to follow for control or elimination. For example, if there were 1,000,000 boll weevils on 5,000 acres of cotton, we would not think of using sterile males. However, if the 1,000,000 occurred on 1,000,000 acres of cotton, I doubt if one could devise a more efficient system of eliminating the population than to release in such area about 100 million competitive sterile males.

Model 3.--Characteristic trend of a population subjected to sterile insect releases which initially overfloods the natural population by a ratio of 50:1. (5x increase for each fertile mated pair)

Generation	Natural population	Sterile population released	Ratio - sterile to fertile	Number of fertile matings
Parent	1,000,000	50,000,000	50:1	9,804
F_1	98,040	50,000,000	510:1	96
F_2	960	1,000,000	1,042:1	<1
Total sterile insects -		101,000,000		

Since we have systems of insect control, which differ in their degree of efficiency - depending on the population density, we can take advantage of this knowledge to properly integrate their use. The potential value of the integration of the two systems discussed can be shown in Model 4.

Model 4.--Characteristic trend of a population subjected to an integrated program of insecticide treatments and the release of sterile insects. (5 fold increase for each mated pair).

Generation	Natural initial population	Insecticide kills 98%	Population subjected to sterile releases: Sterile population released	Ratio - sterile to fertile	Number of fertile matings - pair
Parent	1,000,000 →	20,000	1,000,000	50:1	196
F_1		1,960	1,000,000	510:1	2
F_2		20	400	20:1	<1
	Total sterile insects -		2,000,400		

In this theoretical model we apply insecticides against the parent generation and destroy 98% of the individuals. Then we release sterile insects instead of chemicals to achieve 98% control of the survivors. With the reduced population it now requires only one million instead of 50 million sterile insects to achieve 98% control.

Thereafter each release at the one million rate becomes progressively more effective. In the parent generation the ratio is 50 sterile to 1 fertile. In the F_1 generation the release of 1,000,000 sterile insects would provide a ratio of more than 500 sterile to 1 fertile. This high ratio and reduced natural population would practically eliminate reproduction.

By taking full advantage of the merits of each system in an integrated program we can theoretically achieve complete elimination of a population of 1,000,000 insects by employing insecticides for 1 generation and only about 2,000,000 sterile insects for the next two generations.

This is in marked contrast with the need to apply perhaps 25 insecticide treatments during 6 generations when chemicals alone are used and over 200 million sterile insects during 2-3 generations when sterile insects alone are used.

The question naturally arises, how can we translate the results of the theoretical calculations to actual elimination of an insect population? I think we can show the possibilities by using the boll weevil as an example. The integration of insecticide treatments and sterile male releases for the theoretical elimination of a boll weevil population, is shown in Model 5. I will not go into detail in explaining this model but will merely say that by employing a program of control with insecticides in the fall, which is designed to kill both diapausing and reproducing boll weevils, we can expect to achieve about 98% kill of a boll weevil population before the boll weevils go into hibernation. If 1,000,000 boll weevils is representative of the normal uncontrolled population in the spring on 5,000 acres, the fall treatment would therefore reduce the number to only 20,000 boll weevils on 5,000 acres. Then, if we employed 2,000,000 sterile males during the next two generations in the spring we could achieve theoretical elimination.

Model 5.--Theoretical trend of a low level boll weevil population on 5,000 acres of cotton, when subjected to sterile male releases following a prehibernation control program that reduces the natural population by 98 percent.

Generation	No control 5x increase	Population subjected to insecticides		Populations subjected to sterile releases			
		Before treatment	After treatment	Fertile insects	Sterile males released	Ratio-sterile to fertile males	Number of fertile matings - pair
Parent	20,000 1/	20,000	400	20,000	1,000,000	100:1	99
F_1	100,000	2,000	40	990	1,000,000	1,010:1	<1
F_2	500,000	200	4				
F_3	2,500,000	20	<1				

Relative costs
Insecticides alone - 17 treatments - $25.00 per acre.
Sterile males - 1,000 - 5.00 per acre.

1/ It is assumed that a normal boll weevil population that receives the usual control program as employed by the grower would result in a parent population of 200 boll weevils per acre or 1,000,000 on 5,000 acres; a prehibernation control program producing 98% kill would reduce this number to 20,000 on 5,000 acres or an average of 4 per acre.

The feasibility of using such integrated approach has been shown already by the work of Davich and Merkl which they will discuss during this conference. The major obstacle is the inability at present to produce reasonably competitive sterile males. What costs would be involved in such program? If insecticides alone were used in an eradication attempt it would take about 17 additional insecticide treatments at a cost of about $25.00 per acre following the fall program. If sterile insect releases alone were employed following the fall program, 1,000 sterile male boll weevils per acre should achieve the same effect at a cost of about $5.00 per acre. The theoretical requirements in Model 5 would be 400 males per acre but to allow for reduced vigor 1,000 per acre would be more realistic. Excellent progress has been made by Dr. Gast in rearing boll weevils. The most urgent need to actually try the integrated in a large scale pilot evaluation effort is a way to sterilize males of the boll weevil without serious adverse effects on their mating competitiveness.

The possibility of employing an integrated cultural control and sterile male release program seems extremely favorable for the tobacco hornworm moth, another major insect pest. Model 6 shows theoretically what we might achieve with such program. Mr. Lawson, formerly located at Oxford, N. C., and his staff, have made progress in developing the basic information needed on the population dynamics of the tobacco hornworm moth in order to project a program of the type shown in Model 6. All factors seem favorable. If the projections shown in this model could be released, it should be possible to achieve complete population control of this insect at a cost substantially less than the $10 million now spent for control. Moreover, losses estimated at $25 million each year should be reduced to zero. After the initial effort to completely dominate the population with sterile male releases, it should be possible to maintain continuous control by releasing each year a few million sterile males at a cost that would be only a fraction of the $10 million spent each year by present methods. Of even greater importance from an economic standpoint would be the reduction in losses now amounting to about 25 million each year. Another factor of overriding importance at this time would be the elimination of the need to use insecticides to control this pest on tobacco.

Model 6.--Theoretical trend of a hornworm population on 1,250,000 acres of host plants east of the Mississippi River when subjected to an integrated program of cultural control and sterile insect releases. An untreated moth population would be expected to increase at a 5 fold rate per generation.

Broods	Natural moth population	Sterile moths released	Ratio - sterile to fertile moths	Number of moths reproducing
First year				
1	10,000,000 1/	100,000,000	10:1	909,090
2	4,545,450	100,000,000	22:1	197,628
Second year				
1	247,035 2/	50,000,000	202:1	1,217
2	6,085	50,000,000	8,217:1	0

Estimated cost

Cultural program @ $1.00 per acre	=	$1,250,000
300,000,000 moths @ $5,000 per million	=	1,500,000
Cost for dispersing moths	=	750,000
		$3,500,000

1/ This represents estimated emergence rate of 8 moths per acre following a rigid cultural program the previous fall which reduces a normal expected population by 80%.

2/ This number of moths allows for a 75% mortality due to winter hazards.

I think the sugarcane borer is another major insect that should yield to an integrated control program, involving the use of insecticides or cultural measures plus the liberation of sterile insects. Model 7 depicts the theoretical requirements to control this insect on all sugarcane in Louisiana by using sterile males. Dr. Dahms and Mr. Mathes furnished certain information about the insect, which I used to establish the model. The model shows what might have been achieved if the method had been perfected and applied after cold winters greatly reduced sugarcane borer populations several years ago. If the projections in Model 7 are reasonably valid we could have achieved complete domination over the population at a cost less than the annual cost for insecticides. After achieving complete domination of the population with sterile insects it should be possible to maintain complete control at a fraction of the annual cost for insecticides. Moreover, the annual loss of about $5 million would be eliminated. In the absence of a severe winter kill of the insect it might be possible to lower the natural population by other means and then put such programs into operation.

Model 7.--Theoretical requirements for sterile insect releases to control low level populations of the sugarcane borer in Louisiana on 320,000 acres. The model assumes initial population of 16 moths per acre and a 5 fold increase per generation for an uncontrolled population and for each fertile mating pair.

		Population Controlled by the Release of sterile moths			
Generation	Uncontrolled population	Fertile moths	Total sterile moths released	Ratio-sterile to fertile	Costs of moths @ $2,000/million
Parent	5,000,000	5,000,000	125,000,000	25:1	$ 250,000
F_1	25,000,000	1,000,000	125,000,000	125:1	$ 250,000
F_2	125,000,000	40,000	125,000,000	3,125:1	$ 250,000
F_3	625,000,000 1/	64	5,000	78:1	
F_4	-	0			

Total cost for moths	=	$ 750,000
Other costs	=	$ 750,000
Total 1st year	=	$1,500,000
Estimated cost 2nd year:		$ 300,000

Annual losses due to sugarcane borer reduced to zero.

Insecticides @ $8.00 per acre = $2,560,000

1/ Equivalent to about 2,000 moths per acre.

The above are examples of ways that we might achieve complete control of some of our major insect species. It will take a great deal of work and imagination to develop such methods. We will need to know more about insect population behavior and ways to integrate different methods of control to suppress the populations. One of the most important things to keep in mind is that through the use of sterile insects and possibly with sex attractants which I will discuss next, we have systems of control that can be used to eliminate low populations or prevent the build-up of low populations that were not available before. Since the cost of conventional chemical control is essentially as high when populations are low as when they are high, insect population control by the use of insecticides was often impractical.

Insect Population Control by use of Sex Attraction Responses

During recent months I have given considerable attention to estimating how we might employ the response of insects to sex pheromones in order to achieve insect population control. The possibilities of male destruction or sterilization by employing the response of insects to sex attractants have been under consideration in our Division for some time, and many of you have obtained much information on the behavior of insects in relation to sex attractants.

In order to get a better idea as to how such attractants might be employed for insect population control, I have established hypothetical models to test the control possibilities when employed against certain insects. A few months ago while visiting the Boll Weevil Laboratory, Ted Davich and some of his staff and I discussed the sex attractant work on the boll weevil. In these discussions the possibility of using the living males to control low level boll weevil populations was considered. It has been observed that the male boll weevil attracts the female for mating. (Note report by Dr. Cross). If this is the case and if females will actively seek out males, we should be able to use the living males to attract and destroy the females in the field when the natural population density is low. The next three models, Models 8, 9, and 10; indicate what could be accomplished, theoretically, by taking advantage of female boll weevil responses to the males under field conditions. Model 8 establishes the population trend of an uncontrolled population following a fall program which has reduced the population to an average of 4 boll weevils per acre (2 males and 2 females). Model 9 shows the theoretical effect of a ratio of 10 cages containing males to each free natural male and each female in the natural population. This would involve only 20 cages per acre and the use of 100 male boll weevils per acre per generation. By developing simple, low cost, cage design and an effective way to destroy females attracted to the caged males, it should be practical to eliminate boll weevil populations by employing the living insects as attractants. Obviously, with the boll weevil, as with other insects, the identification and synthesis of the attractant would be the best and most practical approach for using the boll weevil sex attractant. However, this may be difficult and may take time. In the meantime, we should not overlook the possibility of using the living insect to achieve control or elimination of low level populations.

The results in Model 9 indicate that the use of male boll weevils could be as effective or perhaps more effective and practical than to employ sterile males. This is especially significant because of the difficulty in producing sterility in the males.

The most exciting possibility for using attraction of female boll weevils to males, is indicated in Model 10. If the female is polygamous and will normally voluntarily seek males for mating two times before beginning to lay eggs and again within 4 days after egg laying begins, the use of caged males could have a drastic effect in controlling low level boll weevil populations. I think that the use of living male boll weevils offers real possibilities for eliminating boll weevil populations.

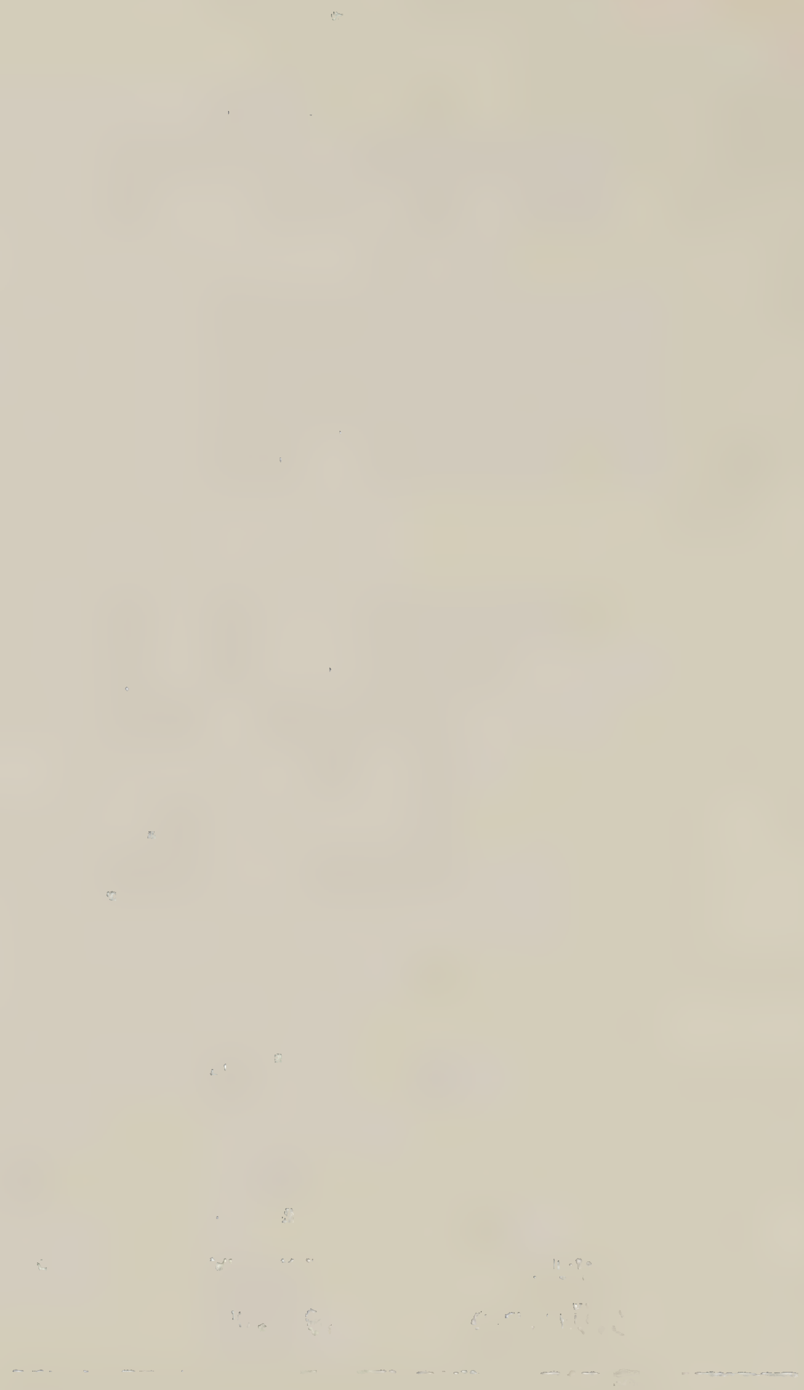
The theoretical effect of male destruction on the reproductive potential of other species has also been investigated by the use of theoretical mathematical models. For such insects I selected the codling moth as an example. The entomologists working on this insect have obtained quite a bit of information on the population densities and population dynamics of the codling moth.

Model 8.--Theoretical trend of an untreated low level boll weevil population on 5,000 acres, consisting of 20,000 boll weevils (10,000 males and 10,000 females), or 4 boll weevils per acre.

Generation	No. of adult females	No. of adult males	No. of eggs deposited	No. of adult progeny
Parent 1/	10,000	10,000	840,000	168,000
F_1	84,000	84,000	7,056,000	1,411,200
F_2	705,600	705,600	59,270,400	11,854,080
F_3 2/	5,927,040	5,927,040	--	--

1/ The parent population consists of the overwintered survivors following a previous fall program that reduced the population by 98%.

2/ It is assumed that F_3 boll weevils will go into hibernation.



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Model 9.--Theoretical trend of a low level population of the boll weevil on 5,000 acres of cotton when subjected to female destruction by the use of caged males. Females assumed to seek males for mating one time before ovipositing.

Generation		No. of adult females	No. of adult males	No. of trap cages	No. of eggs deposited	No. of adult progeny
Parent	Before first mating	10,000	10,000	100,000	0	0
	After first mating	910	10,000	100,000	14,560 1/	2,912
	After first post oviposition mating	83	10,000	100,000	5,644 2/	1,129
						4,041 - Total
F_1	Before first mating	2,020	2,020	100,000	0	0
	After first mating	40	2,020	100,000	640	128
	After first post oviposition mating	0	2,020	100,000	0	0
						128 - Total
F_2	Before first mating	64	64	100,000	0	0
	After first mating	0	64	100,000	0	0

1/ Eggs deposited at rate of 4 per day per female for 4 days.

2/ Eggs deposited at rate of 4 per day per female for 17 days.

Model 10.--Theoretical trend of a low level population of the boll weevil on 5,000 acres of cotton when subjected to female destruction by the use of caged males. Females are assumed to seek males for mating two times before ovipositing.

Generation		No. of adult females	No. of adult males	No. of trap cages	No. of eggs deposited	No. of adult progeny
Parent	Before mating	10,000	10,000	100,000	0	0
	After first mating	910	10,000	100,000	0	0
	After second mating	83	10,000	100,000	1,328	266
	After first post oviposition mating	8	10,000	100,000	544	109
						375 - Total
F_1	Before first mating	187	187	100,000	0	0
	After first mating	0	187	100,000	0	0

Model 11 shows what might be achieved by maintaining a high ratio of caged virgin females in orchards comprising 1,000 acres, provided all males are destroyed when they are attracted to the caged females. Multiple mating by males does not adversely influence the effect of this system of control to any appreciable extent. If a constant high ratio of caged virgin females or the equivalent in extract is maintained for competition with the low level wild female population in attracting males. The results are almost equivalent to that expected for releasing sterile males. Model 11, as projected, would require about 6,000 codling moths per acre per brood. This is well within the practical range in comparison with the cost of chemical control.

Calculations to determine the theoretical effect of a program of the type projected in Model 11 become rather involved and complex. The figures shown are primarily estimates. I have asked Dr. McGuire of the statistical unit to calculate more precisely the effect of various systems of insect population control, involving the use of sex attractants. I have done enough calculating, however, to conclude that male destruction by the use of virgin females or the equivalent in sex attractant extracts is essentially as good, theoretically, as the release of sterile males in controlling insect populations. The results of this study were surprisingly promising. In considering the effect of male destruction in insect populations some of us have been under the impression that due to the polygamous mating habits of male insects and their ability of one male to mate with many females it would be necessary to destroy virtually all males to cause a high reduction in the reproductive potential of the females. This is not the case. So long as caged virgin females or the equivalent in extract are competing with natural virgin females one can expect an adverse effect on reproduction of females that is almost proportional to the ratio of caged female insects to wild females. The sterilization of males instead of killing them would have advantages. The extent of this advantage is under study with McGuire's help, but the advantage of sterilization is not as great as I thought it would be before undertaking the studies on hypothetical populations cited above. With Dr. McGuire's help the effectiveness of various systems of insect control employing insects for their own destruction will be estimated and published.

Model 11.--Codling moth population control by male destruction through use of caged virgin females or female equivalent of extracts. The low level population on 1,000 acres, averages 100 males and 100 females per acre for the first brood. The emergence rate is 5 males and 5 females per day for 20 days. A constant population of 500 caged virgin females (or female equivalent of extracts) is maintained on each acre. A mortality of 25% of the population is assumed to occur each day.

Days	Accumulated uncontrolled mated female population	Accumulated controlled mated female population
1	5,000	50
2	8,750	124
3	11,550	204
4	13,750	284
5	15,300	366
6	16,550	436
7	17,400	498
8	18,050	554
9	18,550	600
10	18,900	640
11	19,150	672
12	19,350	698
13	19,500	718
14	19,650	734
15	19,750	748
16	19,800	758
17	19,850	766
18	19,900	774
19	19,950	780
20	20,000	784

Summary of results		
A. Uncontrolled population		
First brood		
Total female moth days	=	396,300
Total egg deposition	=	19,815,000
Total apples on 100,000 trees	=	200,000,000
Average infestation and stings	=	10%
Second brood		
Estimated average infestation and stings	=	100%
B. Controlled population		
First brood		
Total female moth days	=	13,500
Total eggs deposited	=	675,000
Total apples on 100,000 trees	=	200,000,000
Average infestation and stings	=	0.3%
Degree of control	=	96.7%
Second brood		
Estimated average infestation	=	0.1%
Estimated moth population per acre before hibernation	=	7

The effectiveness of the use of sex attractants in all probability will vary with the population density of the insect population. Like sterile male releases, we can expect increasing effectiveness as the natural population declines if the attractant is maintained at a constant level. This is a great advantage in insect population control. This means, however, that the use of the sex attractant principle involving traps may not be practical when the natural population density is high, even if we have a synthetic sex attractant. Some theoretical calculations were made using the gypsy moth as the "test" insect. Although our Division is not responsible for investigations on the control of this pest, I selected this species for study because we have a synthetic attractant developed by our chemists and research is actively under way by Forest and Plant Pest Control entomologists to investigate the use of the attractant for control.

The results of the calculations are shown in Model 12. On the basis of these studies I have concluded that traps baited with the sex attractant as now used would likely not be practical when populations of the insect are high. However, when populations are low this system should be entirely practical in comparison with insecticides. It seems apparent that for high density populations, for traps to be practical, it would be necessary to use much more attractant per trap than the 12 female equivalents currently used. From a practical standpoint it should be feasible to use as much as 100,000 female equivalents in each trap. Even though each attractant unit may be less efficient when concentrated in this way, it may prove to be the only practical way to use synthetic sex attractants for controlling or eliminating high density populations, because of the large number of traps that would be required if only a low concentration is used per trap. Repellency to males of high concentrations of the synthetic attractant may become a problem.

Model 12.--Theoretical requirements for attractant traps to control populations of insects such as the gypsy moth. The model compares the theoretical requirements for 99% control of high vs. low natural population density levels.

	High density population per square mile	Low density population per square mile
Number of female moths	500,000	500
Amount of female - equivalent attractant needed for 99% destruction of males before mating	50,000,000	50,000
Number of 12-female equivalent trap cups required	4,000,000	4,000
Amount of attractant needed @ 25 micrograms per cup trap	100 grams	100 mg.
Costs @ 2¢ per cup trap	$80,000.00	$80.00
Maximum traps @ 2¢ per trap to be competitive with insecticides @ $640.00 per square mile	32,000	
Required efficiency of each trap	1,550 female equivalents per trap	

Movement and Migration of the Mexican Fruit Fly

J. G. Shaw, Entomologist
Fruit and Vegetable Insects Research Branch
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Little was known about the dispersal and migration of the Mexican fruit fly (*Anastrepha ludens* (Loew)) until 1963 and 1964 when numerous releases were made of tepa-sterilized flies permanently marked with colored lacquers.

Marked sterile flies released from April to June 1963 in Morelos, Mexico, were captured up to 12 months after release. These captures indicated intergrove movement.

From the releases in Morelos of 760,000 sterile males and females from July to September 1963, 8 flies were found to have dispersed from 5 to 11 miles. At this time of the year no subtropical host fruits remain, but only 10 miles away in the foothills deciduous fruits are maturing. These fruits are known to become infested by the native fruit flies.

During the winter of 1963-64, 1,150,000 sterile flies were released in Nuevo Leon, Mexico. Because the winter was damp and cold they moved about very little and soon died, as a result of these severe conditions.

Releases of marked irradiated and tepa-sterilized flies were made in the main citrus area of Texas in February and April, 1964. From these studies it was possible to arrive at an estimate that the native fly population did not exceed 1 per square mile.

Sterile fly movement of 3 or 4 miles within the 45 square mile release area of Tijuana was common. By August, prior to initial releases of flies at Tecate, 8 males were taken there. The nearest point of release for these flies was 23 miles away on the eastern end of the Tijuana area. These flies had to migrate eastward in a canyon from near sea level up to 2,650 feet. Wind currents which are predominately from the west are believed to have aided this fly migration.

Following the coastal land which parallels the mesa, 169 sterile flies dispersed northward from Tijuana into California. Maximum dispersal of 7, 9 and 9.5 miles for 3 individuals were recorded. Several flies were taken in a trap line in the Otay River bed which flows westward parallel to and 4 miles north of the international boundary.

Movement and Migration - Other Tropical Fruit Flies

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The oriental, melon, and Mediterranean fruit flies appear at our borders after traveling thousands of miles in ships or planes. Adult oriental fruit flies can cling to the outside of the windshield of a car (moving up to 70 mph) and be transported long distances. Such movement can be guarded against.

A knowledge of natural adult movement, and how to predict and allow for it is essential in eradication programs. We have released millions of marked flies to study movement, and have often observed the results of natural movement. These species do not normally migrate en masse. The individual fly moves independently toward either food or host odors that attract against the wind, or by allowing itself to drift with the wind. Most flies released from a plane into an 8 mph crosswind at 800-ft elevation drifted about 1/2 mi. downwind. Flies released at 2400 ft. into a 24 mph wind should thus drift 4-1/2 mi. Medflies and melon flies emerging from pupae in ground cages have been caught in greatest numbers 1/4 mi. downwind, so sources of infestation are most likely to be 1/4 mi. upwind of trap catches. However, oriental fruit flies are attracted upwind as much as 1/2 mile by methyl eugenol traps, so natural drift of this species is more difficult to measure. All 3 species have been taken 20-26 miles (16 over water) downwind of a common emergence point. Oriental fruit flies spread over 100 mi^2. of land area. On Guam (210 mi^2.) eradication of a low oriental fruit fly infestation was achieved by first finding all breeding areas with traps, then allowing sterile flies to emerge from pupae placed weekly in cages about 1/8 mile upwind. Flies spread throughout the infested areas. Both sexes move equally well. In the 1962 Florida medfly outbreak, virgin, sexually mature females were as numerous as males beyond the periphery of the infested area. These females responded to trimedlure only when males were very scarce. Marked melon fly males traveled 45 miles in both directions between Guam and Rota, over 37 miles of ocean. Rota has been invaded 3 times since the 1963 eradication by windborne melon flies of both sexes coming from Guam during stormy periods (all outbreaks eradicated). Fruit flies appear to move extensively during the sexually immature stage to food and hosts. Both bring the sexes (including immature sterile flies) together. If hosts are concentrated, different kinds of suppressive efforts can thus be more easily integrated. When widespread, as were oriental fruit fly hosts on Rota, populations concentrated at the downwind end while wind direction was constant, then later spread out over the island in the rainy season when wind direction was more irregular. In Egypt, medflies (presumably airborne) annually reinfest and later disappear from a mixed olive and date grove in a small oasis about 12 miles out in the desert from the Nile delta.

For movement studies we use flies that emerge naturally from pupae at the point of release. Adult releases will not reflect natural behavior. For identification, genetic markers, dye, or radioisotopes are used. The isotope lasts 5 weeks, the dye at least 4 months (see April J.E.E.).

Movement of the Tobacco Hornworm

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Preliminary investigation on the number, habits, and movements of the tobacco hornworm (Protoparce sexta)and tomato hornworm (P. quinquemaculata (Haworth)) was conducted near Oxford, North Carolina in the summer of 1961-62. These studies were to test the possibility that black light traps might be used to reduce populations over large areas.

When 14 light traps were scattered over 25 square miles and moths were marked and released, they dispersed rapidly in all directions. Many flew 3 to 4 miles in one night, and recapture was made as far away as 8.2 miles. The number of moths recaptured fell off sharply with increasing distance from the point of release and the rate of decline was constant. It was calculated that the number of P. sexta males recaptured was reduced 50% with each 0.61 mile of increasing trap distance. P. quinquemaculata was reduced the same in 1.80 miles. Thus, P. quinquemaculata hornworms traveled farther than tobacco hornworms before they were lost.

The calculated half life or the time required for the numbers recaptured to be reduced by half showed that females of both species lived longer or remained in the area longer than males. P. sexta males disappeared faster than P. quinquemaculata males, but the reverse was true of females.

The results of these preliminary investigations were used to design a large scale light trap experiment in an effort to control the tobacco hornworm.

Movement and Migration of the Cabbage Looper

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Since May 1963, BL traps have been in operation in southern Arizona to determine the seasonal flight habits of the cabbage looper and other noctuid moths. Eight traps are within the cultivated areas and four some distance away in the adjoining desert.

In addition to the cabbage looper, records have also been kept on the alfalfa looper and another closely-related looper, Autographa biloba, as well as moths of the beet armyworm, yellow-striped armyworm, corn earworm, and granulate cutworm. Data show that flights of all of these moths reached extremely high numbers in August and September in both the cultivated and desert areas. No suitable host plants of these insects occurred in the desert at this time and therefore these flights were considered to be an overflow from the cultivated area and under these conditions movements into the desert were considered suicidal. Since lettuce and other vegetable crops as well as sugarbeets grown for seed are planted in late August or September the young plants are immediately subjected to heavy infestations of larvae of these moths.

During January and February, 1964, only an occasional moth of the cabbage looper was caught in the traps either in the cultivated area or in the desert. In 1965 very few moths were caught in the traps in the cultivated area during January and February, whereas a considerable number of moths were taken during this period in the desert traps. January and February of 1964 were very dry and comparatively cold, whereas January and February of 1965 were comparatively warm and precipitation considerably above normal. This indicates the probability that during the wet, warm winters we can expect some early spring breeding of the cabbage looper in the desert on annual plants, whereas in dry winters such as 1964 spring breeding of the looper would be confined to the cultivated areas.

In addition to the flight studies of 1963-1965, 25 BL traps are being set up at regular 2-mile intervals over 100 square miles in the southeast portion of the cultivated area of the Salt River Valley. Releases of marked cabbage looper moths for recovery studies will be made at 16 intervening points at regular weekly intervals throughout the year. These studies should not only give additional information on flight habits of this insect but the ratio of marked moths recovered to the native moths caught should give a basis for population estimates which are basic to the development of any method of population suppression or control on an area basis.

Role of Attractants as Applied to Population Suppression
European Corn Borer

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Early sex attractant studies with the European corn borer revealed that an ether extract of tips of mating pairs of moths was attractive to males under specific conditions. The attractant was effective in small cage tests conducted in a plant growth chamber regulated to provide optimum mating conditions for the moths (low light intensity, dropping temperatures, high relative humidity). The attractant was ineffective in 7'x16'x50' outdoor cages in which 100 virgin males were released and their response to the extract was observed during the most active mating period of the moths (10 p.m. to 5 a.m.).

All time available for sex attractant studies since 1962 was utilized in efforts to extract a consistently effective attractant from virgin females and to develop an efficient bioassay.

Recently, experiments designed to reverse the night-day cycle of the insect were successful. Thus, collections of tips of female abdomens can now be made and attractancy tests performed during normal working hours. Results of tests within the last 2 months have indicated the following:

1. An ether extract of tips of virgin female abdomens is attractive to males in small cage tests conducted in a growth chamber.

2. The age of the females from which extracts are prepared is of little consequence as long as the females are at least 24 hours old.

3. Extracts prepared from abdomens of females caged adjacent to males in another cage appear to show the most activity.

4. Even the most active of the extracts in small cage studies produced negative results when subjected to tests in a 14'x20'x30' darkened room in which the temperature was dropping, but the relative humidity was low.

In future studies, efforts will be made to further concentrate the attractant and to develop a more effective bioassay method.

Movement and Migration of the European Corn Borer

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Very little research has been done at the European Corn Borer Research Laboratory on the movement and migration of adult moths. Corn borer adults are capable, however, based on general observations, of moving considerable distances.

The first borers were found in Iowa on the eastern side of the State in 1942, and by 1945 had spanned the State, a distance of approximately 300 miles. This would indicate a migration or movement of about 60 miles per year. The pattern of borer infestation within one county (Boone County, Iowa) has been studied in some detail. Previous investigators of the biology of the corn borer have all emphasized that the heaviest first brood oviposition and infestation occurs in the earliest plantings of corn. This study has also shown that the highest populations per plant occur in the earliest planted corn. However, the data clearly demonstrate that the highest total population does not occur in the earliest corn, but in corn that is planted 6 to 10 days after the earliest planting. This was due to differences in corn acreages. About 22% of the total corn over this period was planted during the first 5 days of the planting period, and 41% planted during the second 5 days. Therefore, corn planted just prior to the middle of the normal planting period was the greatest initial source of second brood moths. Not because the highest first brood populations per acre were found, but because a higher percentage of the corn acreage was planted during this period than other periods of the planting season. Late planted corn usually has a light infestation and a low total acreage, and as a consequence does not constitute an important source of second brood moths. The study indicated that the borers move to fields early in the season that have the tallest and fastest growing corn, but once established on such a field, there is little evidence to indicate that they move from such a crop to later maturing fields.

Heliothis zea - Movement and Migration With Reference to Weather Parameters

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During a study on the movement and dispersal of *Heliothis zea* (Boddie), 9000 marked moths were released at distances of 0.25, 0.5, 1, and 1.5 miles. Approximately the same number of moths, 2 to 4, returned from each distance. Three that returned from 1.5 miles away were released in a clearing surrounded by 30 to 60-foot pine trees. Two of the moths that returned were not taken in the trap but were located sitting in the grass about 10 feet away from the trap. All returns were taken on clear, moonless nights. It is quite obvious to me from watching such traps that moth movement is considerably better on some nights than others. Mr. Jim Valli of the U. S. Weather Bureau and I will have a meteorological data logging system in the field this summer in order to collect accurate weather parameters for moth movement and migration studies. Preliminary results indicate that high dew point temperature adversely affects moth flight.

As Cook (1961) has pointed out, anyone watching a light trap in operation is impressed by the way that moths arrive at the trap in "stop" and "go" spurts. He has shown that changes of temperature as slight as 1° or 2° F. will cause such fluctuations. He calculated that most noctuids have a temperature optimum of 56° to 65° F. and an optimum relative humidity of about 54%. These calculations appear entirely correct for noctuids as an overall average but are slightly low for the corn earworm. Many noctuid species, e.g., the armyworm moth, fly at considerably lower temperatures and humidities than the earworm moth.

Relative humidity is not a good term to use when considering the effect of weather on moth movement, or for that fact, where any insect movement is concerned. Absolute humidity, the actual weight of water vapor per volume of air, is a better term. Even more preferable is the term "dew point", the temperature at which further cooling would cause condensation of water or dew formation. Dew point is especially important since it is the relationship between temperature and dew point that most affect the moth communication system. Experiments in my laboratory have shown that a small dew point temperature spread inhibits moth communications. Significant field data support the experimental work. The lowest moth catches occur early in the morning when the air temperature is closest to the dew point temperature.

Reference Cited

Cook, W. C. 1961. Relation of environment to photosensitivity of insects. U. S. Dept. Agr. ARS 20-10. Response of insects to induced light. 66 p.

Movement and Migration in Populations of Screw-Worm Flies

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Prior to the initiation of the program to eradicate screw-worms from the Southwest, it was believed that these insects dispersed northward from overwintering areas at the rate of about 35 miles per week. The results of subsequent release - recapture experiments indicate that female flies may disperse in excess of 180 miles. During 1962, releases of sterile flies were confined to Texas and New Mexico. By April 15, 1963 screw-worm infestations were recorded 490 miles north of known overwintering areas in Mexico. After extensive releases of sterile flies in Mexico, a 230 mile northward extension of infestations had occurred by April 15, 1964. Releases were extended deeper into Mexico and the northward extension of cases to date in 1965 has been reduced to 122 miles.

There are indications that rapidly dispersing screw-worm flies tend to follow stream courses, especially in arid regions.

Within Field Movements of the Boll Weevil

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Within field movements and home range of boll weevils are influenced by a number of factors including feeding, oviposition, and sex responses. The relative importance of these factors is still under study but some tentative conclusions are now possible.

Attempts to quantitate home range included consideration of several types of measure: (1) total linear distance between successive observations, (2) area of a polygon enclosing the outer points of observation, (3) average of the radii from the geometrical center of this polygon to the point of each observation; and (4) total measures plus and minus movements on x and y coordinates with point 0 at the successive points of observation. Lines connecting the points on the coordinates which represent these latter total measures form a quadrangle which gave the best method of comparing average home range size.

Early season (June 21-August 20) and late season (August 21-October 20) quadrangles were compared for all weevils for which we made 4-8 observations. In both periods quadrangles for males were smaller than for females and those for early season (average for 24 males and 16 females) were larger than for late season (average for 554 males and 351 females).

F1 males observed at intervals of one to several days moved practically none in the first 7 days of adult life but then rather abruptly began considerable movement. Females started moving at an earlier age.

Female boll weevils actively seek males for mating particularly in upwind directions. It is suggested that the longer range movements made by females may often be sex responses. Females may even have a reorientation response if they accidentally fly past the upwind male.

Ecology in Relation to Population Suppression
Pink Bollworm Dispersal

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Pink bollworms may disperse in either of 2 ways: (1) Transport of larvae in seed or other plant parts by man or nature, and (2) flight or wind carriage of adults. Since the means of dispersal by the first method are fairly obvious, this discussion will deal mainly with adult dispersal.

Numbers and sex ratio of adults collected in light traps and flight screens indicate females are most active before cotton squares and after it starts to mature and least during the period of square and boll production. Male activity is probably similar, but not so pronounced. After destruction of stalks, moths become very active and much dispersal undoubtedly occurs.

Evidence of long-range dispersal is collection of adults up to 3,000 ft. in the air by Glick, even over reportedly uninfested areas of Louisiana and Arkansas. Trap plantings in West Texas by Noble and others showed dispersal up to 60 miles from infested fields. Fenton and Owen correlated wind velocity in the heavily infested Laguna area of Mexico with fall infestation in the El Paso area, about 300 miles northward. Lincoln and Glick have indicated correlation of infestation in Arkansas with wind movement from infested areas of Texas.

Little has been done on short-range dispersal. Clark and Glick found released moths had moved 0.3 miles to a light trap in 16 hours.

Population Estimates - Methods Employed
Tropical Fruit Flies

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Formulas and procedures have been developed for utilizing highly attractive male fruit fly lures such as methyl eugenol, cue-lure, and trimedlure (for the oriental, melon, and medfly, respectively) to estimate the species' birthrate (applicable to flies that live long enough to become sensitive to the lure). Approximate sterile fly release rates, in order to overflood isolated areas, can also be obtained.

Standard plastic survey traps baited with 8 ml of methyl eugenol-naled are not significantly competitive with each other if distributed 6 or less per square mile. Eighty such traps/mile^2 will, if well distributed, exhaust the male population before sexual maturity. A lesser number would suffice to exhaust the population if the odors could be confined to contiguous blocks without overlapping, and without competition. This number for methyl eugenol is most likely between 40 and 60. I have arbitrarily used 50 and called it Ec (empirical constant). For cue-lure Ec would approximate 80 and for trimedlure about 120. Ec represents the minimum number of traps that would exhaust the population before any flies could reach sexual maturity without having any 1 trap catch reduced because of competition from traps functioning similarly in contiguous areas. Each would thus catch approximately the same number of flies as would be caught by representative, non-competitive survey traps, although the age complex of the catch would differ.

The non-competitive survey trap catches can be calculated on a per trap day (Cptd) basis or whatever time period is desired. For use in estimating birthrate the traps must have been in position a week or two so that the wild population has adjusted to their presence by elimination of the older flies. Thereafter the catch per trap day can be multiplied by Ec to give the daily estimated birthrate (BR) of males per square mile. Females usually equal males, hence sex (S) equals 2. These data so far refer to the average square mile in a survey area. The area (A) in miles^2 must be included. If we use the 33-square-mile island of Rota as an example we have:

$$\text{Daily BR} = \text{Ec } (50)\ \text{S } (2)\ \text{A } (33) \text{ or } 3300 \text{ Cptd}$$

Before eradication of this species from Rota, the monthly Cptd ranged from 14 to 600. If we use 14 in the formula the lowest daily BR would have been 46,200 flies. The maximum would have been about 2 million. Because the sterilized fruit flies are less effective than normal, we should start with release rates of 20 or more to 1. However, instead of multiplying the BR by 20 we must use a larger figure to compensate for losses peculiar to sterile fly releases. This loss compensation factor (Lc) approximates 100 for the oriental fruit fly, 80 for the melon fly, and will probably be 100 for the Mediterranean fruit fly. Sustained uniform release rates and recovery rates indicate that the loss for oriental fruit flies approximated 80%. With the 20 times overflooding needed this makes up the value of 100 for Lc. The daily required RR therefore would range from 4.6 million in May to 200 million in September. Data representing millions of flies released and hundreds of thousands recovered have been used to test these formulas.

Population Estimates - Methods Employed

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Beet leafhopper

Population estimates of the beet leafhopper are made annually and used as an index as to the probable damage that will be caused by this insect to cultivated crops. Beet leafhoppers are sun-loving, dry-climate insects found in arid and semiarid regions of the Western States. They overwinter as fertilized females in desert, abandoned, and waste areas on plants that germinate in the fall of the year and mature early the following spring, such as mustards. They produce a spring brood that usually matures about the same time as its host plants. This brood moves in search of more succulent plants, such as Russian-thistle, and during this movement, the leafhoppers infest many plants and transmit a virus that causes curly top to several of the cultivated crops. Surveys to determine the population of this leafhopper are made early in the spring with the idea of representatively sampling the overwintered population in desert areas that supply leafhoppers for the cultivated districts concerned.

The methods employed have changed as much over the years as airplane travel. During the early studies, a sweep net was used in the fall to determine the population, and climatic conditions were studied during the winter in an effort to determine the populations that might be present during the spring. Later, population estimates were made in the spring by crawling on the hands and knees over an area and counting the leafhoppers that moved as the hand brushed back and forth over the plants. The next methods used were the spray gun and chain and the spray gun and fork. In 1933, the Hills' cage, which is still being used, was developed by Mr. O. A. Hills. This is a cylindrical cage, open at both ends, covering a 1-square-foot area. When it is placed over the host plants, the leafhoppers jump to the sides of the cage and can easily be counted, which makes possible very accurate leafhopper counts. Stops are made every 3 to 10 miles, depending upon the size of the area to be covered, and randomized samples are taken with the cage. If the leafhopper population averages less than 1 per foot, 50 samples are taken; if they average 1-3, 25 are taken; and if they average over 3, 10 samples are taken. Records are made of plant stand, condition, and distribution at each stop. When the survey is completed, all the data are compiled and compared with those obtained in previous years. For instance, in the Twin Falls area an average population of 1 overwintered female leafhopper in 4 to 5 samples indicates a light movement, 1 in 2 samples indicates a moderate movement, and 1 or more leafhopper per sample indicate a heavy movement. The survey also shows the areas of heavy concentrations that should be sprayed before the leafhoppers move from their host plants. This work has all been done in recent years by Plant Pest Control Division personnel, who now make population estimates in several areas of the Western States.

Population Estimates
Tobacco Hornworm and Budworm

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Three useful variations of standard techniques have been used in studies of tobacco insects. Population estimates of eggs and larvae were made on marked plants and each insect identified by marking the leaf where it was found. Short interval counts by this method will give accurate data on total eggs laid and total mortality over an extended period.

For population estimates of highly mobile insects the method of marking and recapture was modified by marking equal numbers with different colors. By recording color markings of recaptures as many independent estimates of population as there are colors can be obtained.

In some cases it may be necessary to test population control measures against highly mobile insects in areas where isolation is not possible. Dispersal across the boundaries of the control area must be taken into account to estimate the true control. This cannot be done by replication. In the light trap experiment at Oxford a circle having a radius of 6 miles was treated and counts made out another 6 miles on 4 radii. The data were plotted against distance and a curve fitted by regression. The standard error of the regression coefficient can be used to determine significance and the effect of the control measures estimated by calculating the population at the center of the circle and an equal distance outside or wherever the population levels off. The area must be large enough so that the effect of the control measure at the center is not obscured by migration from outside. The whole area samples must be fairly uniform so that the effects of the control measure and dispersal result in a smooth curve gradually increasing from the center outward.

Face Fly Population Estimates

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Face fly (Musca autumnalis) populations are generally expressed as the number of flies per face on cattle. This expression is a basis for comparing populations at different locations and time intervals. It does not have meaning at this time in indicating the breeding potential or the size of the total population.

Information needed in estimating populations was obtained as follows:

From sunrise until sunset - 14 hours and 15 minutes - on a typical summer day in southeastern Nebraska, an observer was with a group of 25 cows with calves on pasture. Throughout the day the number of times and time of day that 6 of the cows defecated was recorded, and a count of the number of flies per face on the cattle was made each half hour. The droppings were collected 3 days later, and the face fly pupae were recovered from them.

The 6 animals defecated 22 times. The range was 3 to 5 times per cow. The number of pupae per dropping varied from 0 to 936. The average was 174 or 523 per cow per day. The average number of flies per face on the 150 cows and 150 calves observed during the day were 18 and 14, respectively.

It was estimated that in this pasture containing 25 adult animals the daily production was approximately 13,000 pupae. Very little breeding occurred in the calf feces because of the size of the droppings. There are no data for use in estimating the number of pupae or adults destroyed by natural causes.

Population Estimate of the Sugarcane Borer, *Diatraea saccharalis*

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In Louisiana approximately 320,000 acres producing about 8 million tons of sugarcane having an estimated value of $64 million is produced each year. As the sugarcane borer destroys about 1/12 of the sugarcane crop, it causes an estimated annual loss of nearly $5-1/2 million. The life history of the sugarcane borer on sugarcane is very similar to that of the European corn borer on corn.

There are 3 main types of surveys for sugarcane borers. One covers overwintering population; another, first-generation; and the other, the infestation at time of harvest. Surveys to determine the number of overwintering borers in Louisiana are made during February. Examinations are made on 10 plantations evenly distributed over that section of the sugar producing area in which the borer is most likely to cause serious damage. Zero to 5 borers per acre are considered to be non-economic, 5 to 25 light, 25 to 100 moderate, 100 to 200 severe, and 200 or more very severe.

Surveys to determine the number of first-generation borers are made mostly as a result of varietal resistance and insecticide studies. They usually consist of number of egg masses found per man-hour and number of borer-killed deadhearted plants per acre, based on examinations of 1/50 of an acre of cane at various locations. A minimum of 5 egg masses per hour or 500 deadhearts per acre normally indicate the need for insecticidal control. Assuming that 2/3 of the borer-killed cane shoots contained live borers should give a fairly accurate figure of the number of borers per acre. For some data accumulated over a number of years, the shoots were dissected and the actual number of borers per sample recorded. The potential increase of full-grown borers from overwintering population to first-generation would be enormous. However, there are so many variable factors such as biological, cultural, soil, rainfall and temperature at different periods, variety of cane, year of crop, insecticides, etc. that it would be extremely difficult to determine the actual rate of increase for any specific set of conditions. Possibly it could be done by measuring all of the known variables and calculating a series of partial correlation and regression coefficients.

Surveys to determine sugarcane borer infestations at time of harvest are made between October 20 and December 15. Up to several years ago examinations were made in the field. In more recent years, examinations have been made at representative mills in 15 of the 16 parishes having mills. If up to 10 percent of the joints are bored, infestation is considered to be very light; 10 to 20, light; 20 to 30, moderate; and over 30, severe. The percentage of crop loss is conservatively estimated to be 3/4 of the percentage of joints bored. There is a good positive correlation between overwintering populations and first-generation borers, and between these and the percentage of joints bored at time of harvest; that is, up until Endrin was used to control the sugarcane borer. Endrin is so effective that its application can cause an early heavy infestation to be very light at time of harvest.

It is impossible to actually count the number of borer stages that have been in each stalk, as many of the pupal cases disappear. Assuming one full grown borer for each 1-1/2 bored joints should give a fairly good figure as to the total number of borers per acre that have matured in the cane during the entire growing season. To convert percentage of joints bored to number of borers per acre we would take 2/3 of the total number of bored joints per acre. For example, in Louisiana the average is 350,000 joints of which 16% are bored. Sixteen percent of 350,000 is 56,000 and 2/3 of 56,000 is 37,333 borers per acre. This number is close to a steady 5-fold increase through the fourth-generation, starting with an average of 50 overwintering borers. However, the rate of increase is not believed to be constant through all generations. It is probably greater early in the season when enemy populations of the borer are low.

Population Evaluation Procedures - European Corn Borer

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Corn borer populations in Iowa are evaluated in three different ways. In the first of these, Boone County was divided into 16 equal 36-square-mile sections. In each of these sections 2 fields were chosen at random for study. Two sampling sites were selected in each field. These were located by starting near the middle of one edge of the field and walking in 45 rows toward the field center. The second site was located by moving 30 rows further into the field and 50 rows to the left of site A. Once a site was located, 2 samples of 5 plants each were selected through the center of each site. Plants within sites were located with white garden stakes and numbered from 1-5 and 6-10, inclusive, at the first site, and the plants at the second site were arranged and numbered from 11-15, and 16-20. All plants at each site were examined twice weekly and the following information recorded for each plant: (1) Oviposition -- the marking of all egg masses, number of eggs in each mass, their stage of development, and determination of their fate. (2) The extended leaf height of the corn. (3) The amount of larval feeding. (4) Predator counts, and the stage of development of the predators.

When the majority of the first-brood larvae were mature, plants 1 through 5 and 11 through 15 were dissected to determine larval survival and the level of infestation of the first brood. Plants 6 through 10 and 16 through 20 retained in each field during the period of second brood activity and borer data collected. These plants were then dissected in the fall to determine second brood and total seasonal infestation.

The second sampling procedure, also done in Boone County, was carried out as follows: All the corn stalks on each of three 1/2000-acre areas were dissected to determine the borer population. The fields used were the same as those used in the previous population study. Sampling was done immediately before harvest, after harvest, in the spring before the fields were disced and planted to oats, and again after the fields had been disced and planted to oats. If the fields used in the previous study were not planted to oats, the nearest adjacent corn field that had been seeded to oats was used for the study. The data collected by these two procedures is adequate for statistical analysis.

The third procedure used was the same as that used by most States to evaluate the borer population in the fall. For this study the State has been divided into 12 districts roughly corresponding with crop reporting districts. Twenty-five fields in each district are samples. These fields are located by placing 25 dots at random in each along main traveled roads within the district. The surveyor estimates the approximate position of the field and then takes the first corn field on the right hand side of the road for sampling. The surveyor walks into the field 25 rows, examines 25 plants to determine the degree of infestation, and splits 2 stalks to determine the actual amount of infestation. This sampling results in the figure that is usually reported as borers per 100 stalks. The sampling procedure of most value for determining the success of population management procedures would be the second.

Population Estimates - Methods Employed

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Very few boll weevil population estimates, even among research personnel, are based on actual counts of adults, larvae or pupae. The 3 exceptions are: (1) Presquaring counts of adults on one or more 50-foot row lengths per plot, (2) counts of hibernating weevils in a preselected number of square yards of forest litter, and, (3) the rarely practiced method of shagging a preselected number of row feet of cotton and counting the captured weevils.

During the fruiting period a representative sample of squares is selected from fields randomly, on a diagonal, from several representative points or preselected number of plants. 100-500 squares per field is the usual number examined. Feeding and oviposition punctures both are counted and the results expressed as % punctured squares.

These remarks, with one exception, pretty well sum up current methods of obtaining boll weevil population estimates across the cotton belt. The exception is the point sample method being used in Arkansas. In this method a starting place is marked on a row of cotton and all squares large enough for weevils to attack are examined until 50 squares have been looked at. The length of row needed to obtain the sample is measured. The procedure is repeated at 4 to 8 points within the field. The % punctured squares then is computed and may be used as a population estimate. This method should be superior to the others in obtaining population estimates since it measures the total number of squares present as well as the % punctured squares.

Methods of Pink Bollworm Population Estimation

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Estimates of the larval populations of pink bollworm may be divided into three general categories: (1) Rosette bloom counts, (2) boll population estimates, and (3) overwintering population estimates. Until recently much of the counts of populations in blooms before bolls formed were based on percent blooms infested or rosetted, which is of little value for estimating population density. Recently, more emphasis has been placed on rosette blooms per row-foot, which can be converted to population per acre. For accurate estimation of population density in blooms, counts must be made daily until numbers of larvae in this site become insignificant compared to the total population.

The percent bolls infested has been a common record taken for insecticide trials, but is of little use for population density estimation. Other common records made are numbers of larval mines or exit holes per boll. These are valuable if the number of bolls per unit area is known. For some special studies, larvae per boll, plant, or unit area may be recorded. This is difficult because young larvae are hard to see. No attempts have been made to use any statistical basis for any of these methods of sampling.

Determination of density of overwintering populations in seed requires considerable labor. X-ray examination has helped this, but is not completely reliable. Also, after the crop residue is plowed, soil examination is necessary to locate these larvae or those which form free soil cocoons. With these problems, it is difficult to take sufficient samples for reliable population estimates. Work has been done on optimum allocation sampling, but the data is limited.

Relative abundance of adults has been determined by light traps, sex attractant traps, flight screens and airplane traps. There has been little work done on estimation of actual population density.

Possibilities for Application of Infrared and Microwave for Population Control: Theoretical and Experimental Studies of Arthropod Spines as Dielectric Tubular Waveguides, Particularly the Thermoelectret Properties of Waxes

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This is a short summary of research to be presented in a larger report on insect spines as waveguides.

M. Eguchi, a Japanese physicist, demonstrated in 1922 that certain dielectric mixtures exhibit polarization when allowed to solidify in the presence of heat and an electric field. Such ploarized dielectrics, whether thermo- or photo-, were termed electrets. Physicists later showed that the best thermoelectrets were certain waxes such as bee's wax, carnauba wax, polar hydrocarbons and certain esters and alcohols. The electrical conductivity of thermo- and photo- electrets can be increased or decreased by irradiation with certain wavelengths of the electromagnetic spectrum. Physicists have shown that a thermoelectret charge depends upon the humidity of the air. Storage of a thermoelectret in excessive humidity will produce a sharp fall in charge. Long storage at humidities greater than 80% may produce irreversible changes.

It is well known that the insect cuticle is covered with a waxy layer and, thus, is potentially a polar thermoelectret. Since such a waxy semiconductor fits the waveguide configuration, I have postulated for insect communications, noctuid moths and wolf spiders were subjected to both UV radiation and high dew points. Both parameters would be expected to depolarize a waxy thermoelectret. Subjection to a high dew point would assure a thin film of condensed moisture on the arthropod's spines. Both UV and high dew point caused the test arthropods to initiate violent cleaning motions of moth antennae and spider pedipalp. Both parameters essentially "short circuit" the arthropod's sensory system and the arthropod in turn trys to remove the interference. This substantiates my theories concerning insect spines as thermoelectret type dielectric tubular waveguides.

It is my belief that arthropods are like satellites programmed by the subtle radiation of nature to fit certain portions of the biosphere. Insects have numerous and diverse types of spines and optical systems. For instance, just because a bee flying in the daytime has been shown to have the ability to distinguish colored flowers does not mean that a moth flying at midnight is programmed to do the same thing and thus, could not possibly detect infrared or microwave frequencies. Each insect has an identity of its own. Each has spines of different sizes and configurations and is thus programmed to a different portion of the electromagnetic environment. This should be obvious but apparently is not.

This research has tremendous practical application, but such applications will never be realized until complete electromagnetic radiation profiles have been determined for each insect species and frequencies charted for every phase of its activity.

In summary, and as an example of what I term an electromagnetic profile, I present the table below.

Electromagnetic Profile of a Hypothetical Insect Species (nocturnal moth, larvae inside fruit of plant).

Radiation factors	Time of moth activity	Flight limited by	λm to prevent diapause, hrs. required	Spine transducers response λm	Optical transducer response λm	Stimulation time & λm for restimulatable parameters	Communication frequencies total and scent
Weather	9-12 PM	dew point temp. spread of -0.8°F or less		Depolarized by 0.25 μ & -0.8°F D.P.			
Atmospheric windows	2.2 μ good 4 μ good 10 μ good			0.25 μ poor. rest good	good for all	0.5 μ good 0.36 μ fair	good
Plant windows	1.3 μ good		1.3 μ good	none	none	0.5 μ poor 0.36 μ none	poor
Freque-cies		light above 0.008 langley, 0.5-0.7 μ	1.3 μ at 14 hrs	2.2, 4.2, 10.3, & 50 μ 61 KMc*	.5 μ 4 μ 10.2 μ	Thermoelectret 0.5 μ, 3 hr. photoelectret anthracene 0.36 μ, 2 hr	2.2-4.2 μ host plant 10.3 & 50 μ total moth 61 KMc scent

*Scent sensitivity increased by stimulation of molecule by 1 μ (2600°C).

Suppression of Hornworm Populations with Light Traps

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Numerous investigators have studied the response of insects to light (ARS 20-10, July 1961) (Nelson & Seubert, 1965). However, limited research efforts to utilize the attraction of nocturnal insects to ultraviolet radiation as a method of control have met with limited success or acceptance. Likely, failures were due generally to continuous infiltration of insects from outside the small treated areas. It is unfortunate, in view of the serious problems of insect resistance to insecticides and the environmental hazards of continued use of persistant chemicals, that greater emphasis has not been placed on the use of light traps for insect control.

In 1961 Lawson and co-workers, in cooperation with AE, (ARS-33-91) initiated a study near Oxford, North Carolina, to evaluate the use of blacklight traps against the tobacco hornworms, _Protoparce sexta_ (Johannson) and _Protoparce quinquemaculata_ (Haworth). These results showed that hornworm moths were capable of considerable movement and that a test area at least 6 miles in diameter would be required with a trap density of 3 per square mile. Check traps were established on 4 radii at right angles from the center of the circle to 6 miles beyond the circumference. Egg and first instar larvae and damage counts were made in tobacco fields on radii lying between the check trap radii. Results showed that hornworm populations and damage were lowest at the center of the area and gradually increased towards the circumference. Although hornworm incidence increased more rapidly beyond the circumference, a plateau was not reached at 6 miles beyond (or 10 miles in 1964) the treated area, indicating that influence of the treated area extended at least 6 to 10 miles beyond the circumference. Estimated percent reduction in tobacco hornworm populations and damage between the center and 6 and 14 miles outside the treated area were as follows:

	6 Miles			14 Miles
	1962	1963	1964	1964
Mean Catch of Tobacco Hornworms				
Males	76	94	77	89
Females	55	64	75	89
Hornworm Eggs on Plants	58	83	71 1/	82 1/
Plants Damaged by Hornworms	--	--	77 1/	89 1/

1/ Observations made on 48 half-acre plots not treated with insecticides.

Reduction in trap catches for the tomato hornworm was similar to those for the tobacco hornworm.

Applications of insecticides by tobacco farmers for hornworm control inside the area in 1963 were reduced by 90 percent compared with the outside. In 1964, records obtained on applications for all tobacco insects showed over a

50 percent reduction. In 24 check plots, ½ acre in size, inside the area, only one field showed larval counts justifying application of insecticides. However, within 2 days parasites and predators had reduced the population to a non-economic level and no insecticides were applied.

Following installation of light traps in the test area in 1962, farmers voluntarily increased the amount of stalk destruction, and in 1963 all farmers within the test area were requested to destroy stalks before the overwintering broods could develop.

Although it is difficult, if not impossible, to accurately assess the relative importance of light traps, stalk destruction, and parasites and predators, it is obvious from the Oxford data that an integrated control program of this type can greatly reduce the need for insecticides.

A project to test the effect of light traps on an isolated population is being initiated in cooperation with AE on the Island of St. Croix, U. S. Virgin Islands.

References Cited

Lawson, F. R., C. R. Gentry, and James M. Stanley, 1963. Effect of Light Traps on Hornworm Populations in Large Areas. ARS-33-91.

Nelson, S. O. and J. L. Seubert, 1964. Electromagnetic Energy and Sound for Use in Control of Certain Pests. (Presented at the 131st Annual Meeting of the American Association for the Advancement of Science, Montreal, Canada, December 26-31, 1964).

Symposium 1961. Response of Insects to Induced Light. ARS-20-10.

Ultraviolet Radiation as an Attractant for Adult Horn Flies

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Horn flies (Haematobia irritans (L.)) are equally attracted to Blacklight Blue and Daylight fluorescent lights in cages in the laboratory. A comparison was made of the simultaneous attraction of horn flies from 3 cows in isolated, screened stalls, to Blacklight Blue (BLB), Blacklight (BL), and Daylight (D) fluorescent lights. Of the total flies attracted from the animals to the lamps, about 85% went to the BLB, 13% to the BL, and 2% to the D.

In order to determine whether or not the ultraviolet radiation from BLB was more attractive than a cow to horn flies released into a dark building containing both attractants, the "Y" tube principle (Fingerman 1952) of a release chamber and 2 adjacent rooms containing the attractants was used. The interior of the building contained a tier of 3 rooms of similar dimensions, with 40-inch-square windows in the 2 internal walls. When the fly release cage was in the center room, it was located where the emerging flies had a direct line of flight to both the cow and the BLB lamp in the adjoining rooms. The locations of the animal, light, and cage were changed after each test, and for one-third of the releases the flies had to pass the cow to reach the lamp. Horn flies were 10 to 25 times more attracted by light than by the cow, regardless of the location of the light.

Use of BLB as a field attractant seemed to be limited in effectiveness by size of lamp tested, competition with other sources of light, and distance between light and cows. When animals were within the beam of light on moonless nights, the flies were attracted to a BLB lamp.

BLB radiation combined with some insecticides is being evaluated as a means of controlling horn flies on dairy cows. The combination is used in a modification of a horn fly trap designed by USDA in 1940. The trap is in the preliminary stages of development.

Ultraviolet radiation is being used in the laboratory to augment the efficiency of the WHO mosquito test kit used to screen compounds for controlling horn flies. The light is used to attract flies to treated filter paper covering the screened end of the exposure cage, and to move the flies from holding cage to exposure cage and back, so that flies need not be blown from cage to cage. The kit has been tested with stable flies (Stomoxys calcitrans (L.)) with similar results. Flies of both species can be held on the treated paper as long as the light is on beyond the paper.

Ultrasonic Sound and the Bollworm Moth

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Electrophysiological studies of the acoustic receptors in the tympanic ear of the bollworm moth, Heliothis zea (Boddie), show that sound stimuli in the 6 kcps to 120 kcps range are effective acoustic sense cell stimuli. Acoustic sensitivity tests have shown that the first A-cell of the bollworm moth is most sensitive to ultrasonic sound stimuli from 18 kcps to 25 kcps freqencies.

In a field test using a black-light trap containing an ultrasonic sound speaker operating at 20 kcps to 26 kcps frequencies and a control trap containing a dummy speaker, the silent trap caught 4 times as many tympanate moths as did the trap with the acting speaker.

In behavioral tests using a condenser speaker supplied by Edsel Harrell of the Southern Grain Research Laboratory at Tifton, Georgia, it was found that H. zea moths within 10 to 30 feet of the speaker operated at frequencies of 20 kcps to 50 kcps, dived or looped to the ground when the ultrasonic sound was beamed at them. Moths about 40 to 60 feet from the speaker flew a fast and rather straight line retreat from the sound source when the ultrasonic sound was beamed at them.

These acoustic studies indicate that ultrasonic sound may be an effective means to suppress or prevent economic damage caused by larvae of tympanate moths. More detailed work is needed to elucidate the finer details on the effect of ultrasonic sound on moth movement, mating, and oviposition.

Blacklights for Bollworm Control

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Extensive use of the Onamia blacklight trap for bollworm control was made during 1964. These traps, each equipped with 4 circular, 28-watt black lamps and a suction fan, were placed around the margin of fields and separated by a distance of about 500 feet. A trap served from 5-7 acres.

In the Pecos, Texas, area the Texas Agricultural Experiment Station estimated 10,000 acres under lights. No specific records were taken by Federal and State entomologists, but the general opinion among farmers was that the traps had merit. A commercial checker made records on 1330 acres of lighted and 285 acres of unlighted cotton in this area. He reported $2\frac{1}{2}$ times more eggs laid on the unlighted cotton and 37% less worms on the lighted. Also the lighted fields had 1/3 less applications of insecticides.

Observations made at Tucson, Arizona, on 2 lighted and one unlighted cotton field revealed fewer bollworms, salt-marsh caterpillars, beet armyworms, and cotton leaf perforators on the lighted fields as compared to the unlighted. Differences in cabbage looper numbers were minor.

The Stanford Research Institute made extensive comparison of lighted to unlighted plots in California. They reported no difference in lygus bug populations but reported less bollworms on the lighted as compared to the unlighted in most cases.

Measurement of Distance of Attractiveness of 15-Watt Black Lights to Noctuid Moths

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Preliminary work at Mesa, Arizona, with release and recovery of marked cabbage looper moths indicated that the maximum distance of attractiveness of 15-watt black lights was approximately 50 feet. Based on this hypothesis nine 15-watt BL traps were arranged in three triangles, each well separated from the other. In the first group the sides of the triangle were 50 feet; in the second group the sides of the triangle were 100 feet, and in the third, 200 feet. Traps were set up at the points of the triangles in each case, and by this arrangement the assumed field of attractiveness overlapped approximately 50% in the 50-foot group. In the 100-foot group the fields of attractiveness touched with no overlap and in the 200-foot group the assumed fields of attractiveness were well separated.

If the hypothesis is correct that 50 feet is the maximum distance of attractiveness of the lights, then the per-trap-per-night catch in the 50-foot group should be approximately one-half that of the 200-foot group and the per-trap-per-night catch of the 100-foot group should not be materially different from the 200-foot group.

Data from these studies indicated that the maximum distance of attractiveness of these lights to the cabbage looper, beet armyworm, yellow-striped armyworm, and corn earworm is between 50 and 100 feet, while the maximum distance of attractiveness for the granulate cutworm was indicated at something less than 50 feet.

Progress in the Isolation, Identification, and Application of Sex Attractants for Insect Population Suppression

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The investigation of insect sex attractants has increased by leaps and bounds within the past five years. Up to the present time, 155 species of insects have been reported in which the female produces a sex attractant for the male, and 55 species in which the male produces a sex attractant or excitant for the female (1). The breakdown by Orders where the attractant is produced by females is as follows: Isoptera 2, Diptera 4, Orthoptera 10, Coleoptera 14, Hymenoptera 17, and Lepidoptera 108. For those species in which the attractant is produced by the male, the breakdown is as follows: Neuroptera 1, Hymenoptera 1, Hemiptera 2, Mecoptera 2, Coleoptera 3, Orthoptera 3, Diptera 3, and Lepidoptera 40.

In the three years since the Planning and Training Conference on Attractants was held, entomologists of this Division have demonstrated the existence of sex attractants in at least 24 species of insects.

Those insects whose sex pheromones have been identified are the silkworm moth (Bombyx mori), gypsy moth (Porthetria dispar), pink bollworm moth (Pectinophora gossypiella), greater wax moth (Galleria mellonella), giant water bug (Lethocerus indicus), bumblebee (Bombus terrestris), and possibly the honey bee (Apis mellifera). Isolation studies are in progress in the Department on the sex attractants of the following species: Codling moth (Yakima, Wash.), Cabbage looper (Riverside, Calif.), European corn borer (Ankeny, Iowa), Peach tree borer (Ft. Valley, Ga.), Lesser peach tree borer (Vincennes, Ind.), Boll weevil (State College, Miss.), Fall armyworm (Tifton, Ga.), Banded cucumber beetle (Beltsville, Md., and Charleston, S. C.), Housefly (Beltsville, Md., and Corvallis, Oreg.), Southern armyworm (Beltsville, Md., and Brownsville, Texas), Oriental fruit moth (Beltsville--Cooperative project with Canada Dept. of Agr.), Omnivorous leaf roller (Beltsville), Carpenterworm (Beltsville, Md., and Stoneville, Miss.--Cooperative project with Forest Service).

Two university grants are now being negotiated for the isolation of sex attractants in cooperation with the Fruit Insects Branch. These are at the University of Wisconsin on the tobacco hornworm moth and at the University of Michigan on the tobacco budworm moth.

At Beltsville we have very recently succeeded in identifying the pink bollworm moth sex attractant from 800 micrograms of pure material obtained from nearly one million virgin female moths provided by the Brownsville Laboratories of Cotton Insects Branch. We are attempting to synthesize the attractant by a 16-step procedure and have thus far surmounted the first four steps.

Work in the field of population suppression with sex attractants is still very much in the experimental stages, but certain studies have been carried out along these lines. Ambros (2,3) as far back as 1938 described field tests showing that traps baited with live female nun moths caught thousands of males. For example, a total catch of 385,000 male nun moths was obtained in an area of 757 square hectares in 49 days using 480 traps, each baited with 5 live females replaced weekly. Work along similar lines was reported in 1937 for the gypsy moth by Prüffer (4).

In 1960 Coppel et al. (5) reported that one live virgin female introduced pine sawfly placed in a cage suspended from a tree in the field attracted more than 7,000 males between 11 a.m. and 4 p.m. She continued to attract males at approximately 1,000 per day until she died on the fifth day, after which small numbers were caught for the next 3 days. Males could be lured 200 feet out of the forest over an open field.

Bobb (6) reported that in 1963 the population of the Virginia-pine sawfly (*Neodiprion pratti pratti*) declined to an extremely low point, whereas in previous years population explosions of this insect had occurred. Although both males and females appeared to be completely normal in vigor and behavior in 1962 and 1963, none were observed in copulation and only occasionally was a female observed ovipositing. Whereas in 1960 a very high percentage of females mated, in 1963 only 2.5% mated. The population decline has been attributed to the loss of sex attractiveness by the female, but no explanation could be offered for this loss.

Literature Cited

(1) Jacobson, M. *Insect Sex Attractants*, Wiley, New York, in press.

(2) Ambros, W. Die biologische Nonnenfalterkontrolle 1937. *Centr. ges. Forstwesen*, 64: 209 (1938).

(3) Ambros, W. Einige Beobachtungen und Untersuchungen an der Nonne im Jahne 1938. *Ibid.*, 66: 131, 166 (1940).

(4) Prüffer, J. Weitere Untersuchungen über die Mannchenanlockung bei *Lymantria dispar* L. (Lep.). *Zool. Polon.*, 2: 43 (1937).

(5) Coppel, H. C., et al. Evidence for a potent sex attractant in the introduced pine sawfly, *Diprion similis* (Hymenoptera: Diprionidae). *Ann. Entomol. Soc. Am.*, 53: 510 (1960).

(6) Bobb, M. Apparent loss of sex attractiveness by the female of the Virginia-pine sawfly, *Neodiprion pratti pratti*. *J. Econ. Entomol.* 57: 829 (1964).

Male Annihilation Technique to Eradicate Tropical Fruit Flies

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Late in 1949 we found that the oriental fruit fly male would feed avidly on methyl eugenol, that any one of several organic phosphate poisons could be included in small amounts to kill males, that males became responsive long before they reached sexual maturity, and that some could be attracted up to distances of $\frac{1}{2}$ mile. Later our tests demonstrated that substantial suppression could be attained in areas as small as 3 to 6 square miles. It is essential that the lure attract and kill all male flies before any reach sexual maturity. This effectiveness must be maintained until all females disappear. Our first eradication experiment in the Bonin Islands failed because maintenance of the lure odor was too frequently interrupted by unavoidable delays between lure drops. Male populations were depressed as much as 99 percent. Virgin, sexually mature females were found to respond to the lure in highly significant numbers when the male population approached extermination.

The method was applied to the island of Rota in 1962-63. It successfully demonstrated for the first time that an isolated infestation of a long-established (30 years) pest could be eradicated by its use. Fifteen biweekly applications of a methyl eugenol/3% naled solution impregnated in cane-fiber insulating board squares were made to the 33-square mile island. Small fiberboard squares were dropped from an airplane at the rate of 130 per square mile over lines 1/5 mile apart. Larger squares were hung in village areas avoided by the plane. Only 4.5 g of poison and 90 g of lure per acre were applied during the 8-month period. Fly catches in traps averaged 262 per trap day for the 2 weeks before the first lure drop. After 1 generation the reduction in males was 99.6% and after 2 it was 99.999%. The last fly and last infested fruit on the island were each found about $5\frac{1}{2}$ months after the start. Early in the experiment up to 90% of the small number of flies still being caught in the traps were females. The island has remained free of the oriental fruit fly for more than two years, during which period 100 survey traps have been maintained. Before eradication this number would have caught more than 5.5 million males per year.

The method is now being applied to Saipan, Tinian, and Aguigan, involving 90 square miles with the object of completing oriental fruit fly eradication in the Marianas. The last fly to appear on these islands may already have been caught after only 6 lure drops (only 3 flies have been caught to date in April).

The method will be particularly useful for eradicating incipient outbreaks of the oriental fruit fly should they occur in the continental United States. Survey traps using the same lure accurately measure progress and can lead one to persistent "hot spots." The end point is easily determined without searching fruit for infestations. The response of females towards the end greatly shortens the period of time that suppressive efforts must be continued beyond appearance of the last male. The method is being adapted to utilize cue-lure for the melon fly and medlure for the Mediterranean fruit fly. Incorporation of thickening agents with the male lures will permit their distribution as thick, viscous droplets that will remain effective on foliage for 1 month or longer. Tests indicate that the volatility of cue-lure and possibly even medlure is so low that when impregnated on wafers and the wafers allowed to lie on the soil, efficiency of the lure is less than when on foliage.

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The Synthetic Gypsy Moth Sex Attractant, Gyplure, and Its Potential Role as a Population Suppressant

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Gyplure has been field tested as a gypsy moth population suppressant in two ways. The attractant has been applied to infested areas in an attempt to confuse male moths to prevent or reduce mating. Gyplure has also been tested in an effort to annihilate or substantially reduce male moth populations by saturation trapping.

In a confusion test conducted in 1961, gyplure was broadcast by aircraft over an infested 400-acre island in both liquid and granular formulations at the rate of .8 ounce actual attractant per acre. Neither formulation attracted male moths, however, and mating activity was considered normal. The ineffectiveness of this gyplure later was attributed to the masking effect of certain impurities. A somewhat similar confusion test scheduled for 1964 was cancelled when laboratory and field bioassays revealed that the gyplure scheduled for use did not retain its attractiveness for an adequate period.

In 1964 the saturation trapping technique was extended to include aerial trap drops over lightly infested areas of Pennsylvania, New York, and New Jersey. Three series of drops spaced at three week intervals were made on the assumption that the lure would remain active for approximately three weeks. The traps, specifically designed for dispersal by aircraft, were spaced at 1/16 and 1/8 mile intervals. Release of the traps at the desired spacing was accomplished by an electrically driven ejection device designed to fit into the baggage compartment of a Cessna 180 aircraft. Evaluation of these saturation trapping tests and corresponding tests with hand placed traps was complicated by the instability of the gyplure used in the initial stages of the test. However, sufficient numbers of moths were caught to demonstrate the feasibility of this technique and to justify continuation of the tests.

Both confusion and saturation trapping techniques will be further explored in 1965. In addition, gyplure will be investigated in the laboratory for possible use in combination with a chemosterilant such as tepa.

In order to determine the effectiveness of the gyplure scheduled for use in the 1965 studies, it is planned to field test the material in Spain this spring in areas of early moth emergence. Information gained from these preliminary trapping studies will make it possible to determine the optimum concentration of gyplure required for tests in this country and will indicate the need, if any, for repeated applications.

Role or Potential Role of Attractants in Population Suppression - Pink Bollworm

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The greatest potential role for the pink bollworm sex attractant in an eradication program will be as a survey tool and/or as a method to annihilate males. The male annihilation technique is especially intriguing when integrated with a sterile female release. Hypothetical calculations show that when sterile female release alone at a 9:1 ratio controls 74% of the population, integrating this method with a male annihilation technique, where only 75% of the males are trapped, would result in a total 93.4% control.

Since pink bollworm females can be sterilized with metepa and are competitive under laboratory conditions, the above integrated approach is more than hypothetical.

In field attractant studies, 49 lure traps containing 50 female equivalents each collected 2039 males prior to cotton blooming and more than 12,700 males through the test period; however, no control of the pink bollworm population was achieved. The above results were primarily due to lack of isolation from moths outside the trapped area.

Potential Role of Attractants in Population Suppression: Fall Armyworm

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and
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The fall armyworm, Spodoptera frugiperda (J. E. Smith), causes a large amount of damage to corn in the southern states annually but does not pass the winter in any of its stages except in southern Florida and southern Texas. It is potentially possible to suppress or limit the spread of this insect in the United States due to a combination of factors, i.e., limited range of the insect in winter, sensitivity of all stadia to low temperature, relatively low population density in its winter range, a potent sex pheromone (mating stimulant), and a chemosterilant that acts on contact. However, suppression is impractical at the present time due to such unknowns as flight range of the moth, attractive range of the pheromone, and identification and synthesis of the pheromone. Research is currently under way on these problems.

Our research has shown that the female produces a substance in the last 2-3 abdominal segments that is capable of inducing a mating response in the male moth. Extraction of the tips of 12,000 females yielded 100 ug of a highly active compound, i.e., about 0.008 ug per moth. This is approximately 1/3 of the amount reported for the gypsy moth. We have additional unprocessed material from about 13,000 moths. This includes pheromone "trapped" for extraction by 4 procedures. (1) Paper liners from moth holding cages, (2) lanolin-lard coating from glass plates over which air was pulled from the cage, (3) cold-trapped effluent air, and (4) abdominal tips from moths after 4-5 days in the air-trapping cages. The total quantity of pheromone is unknown; however, bioassay has shown it to be biologically active. Concentration and cleaning are presently under way.

Some recent results are as follows: (1) Male moths of different ages were exposed to 0.2 moth equivalent (M.E.) of 3- to 6-day-old females. 1-day-old ♂, 48% reacted; 2-day-old ♂, 86% reacted; 3-day-old ♂, 93% reacted. (2) 3- to 6-day-old ♂ exposed to 0.2 M.E. of different aged females. Extracts from ♀ 12 hours old, 2% ♂ reacted; ♀ 24 hours old, 32% ♂ reacted; ♀ 36 hours old, 80% ♂ reacted; ♀ 48 hours old, 98% ♂ reacted. (3) 3- to 6-day-old ♂ exposed to different concentrations of 3-day-old ♀ extracts. 0.02 M.E. (10^{-4} ug), 98% ♂ reacted. 0.002 M.E. (10^{-5} ug), 88% ♂ reacted; 0.0002 M.E. (10^{-6} ug), 66% ♂ reacted; 0.00002 M.E. (10^{-7} ug), 20% ♂ reacted. (4) In box 3'x 2' x 1.5' a quart ice cream carton trap caught an average of 30% of the moths in the box each night for 5 nights, only 1 in the untreated control in the same period.

Studies of the Natural Sex Attractant of the Lesser Peach Tree Borer

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Studies were initiated at Vincennes in 1963 to determine whether the attractiveness of caged virgin females of the lesser peach tree borer, *Synanthedon pictipes* (G. & R.), was strong enough to attract a number of males and whether a high percentage of males so attracted could be caught on sticky board traps. The percentage of virgin females naturally attractive, when placed in cages in the field and the duration of attractiveness, was to be determined. Studies were begun to determine the location of the attractive substance in or on the female body and the possibility of its removal for further chemical study. Of prime concern, also, were studies to determine methods of maintaining or producing populations adequate for the continuation of these studies.

Initial investigations revealed that females attracted an average of 23 males each, when confined in cages in the field, and that 59 percent of the females were attractive. Up to 70 males have been attracted to a single caged female within a 30-minute period. The attractive substance is located somewhere on the terminal three segments of the female abdomen. The time of maximum natural attractiveness has been from 9:00 to 11:00 a.m. C.D.T., but males may be attracted to females at any time during the day.

In 1963 studies showed that males were attracted to females from distances as far as 500 feet. In 1964, 26 of 100 marked male moths were recovered from traps baited with virgin female moths. Males were released at a distance of $2\frac{1}{4}$ miles from the traps. The first capture was made within 24 hours of release time. In 1964 efforts were made to trap males from a block of 235 peach trees, which was approximately 1 mile from the nearest peach orchard. Data secured indicate that males were attracted, not only from the block in which females were placed but also from surrounding orchards. The borer population in this block increased, rather than decreased, in spite of the grower's regular spray program.

While we are depending on the use of borer-infested wood as a supply of moths, an artificial diet has been developed from which we receive a return in adults of approximately 50 percent of the larvae fed. Recent investigations have shown that the borers may be readily reared on small thinning apples. Diapause, while initially encountered, has been prevented by rearing under conditions of constant light.

Other biological investigations are being made, including weights, measurements, and duration of the various instars of the insect.

Role or Potential Role of Attractants in Population Suppression: Tobacco Hornworm

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It is well known that virgin female moths of the tobacco hornworm, *Protoparce sexta* are attractive to male moths. During the summer of 1964 virgin females were placed with blacklight insect traps. These were gravity-type traps, using a 15-watt ultra-violet flourescent tube. The trap is described in detail by Stanley et al. (1964). 1/

From one to 30 virgin female moths were placed with blacklight traps. For every 94 male moths caught by a light trap alone, the addition of each virgin female, up to 10, increased the male catch by 89. The male catch did not increase proportionately when the number of virgin females was increased from 10 to 30.

1/ Stanley, J. M., F. R. Lawson, and C. R. Gentry, 1964. Area Control of Tobacco Insects With Blacklight Radiation. Tran. Amer. Soc. Agri. Engineers 7:125-27.

Mass Rearing and Distribution of Parasites, Predators and Diseases
General Review of Past Efforts and Current Plans

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The following discussion is limited to parasites and predators since work with diseases is more recent and well known.

DeBach and Hagen have recently reviewed the subject in the book entitled, "Biological Control of Insects, Pests, and Weeds." The egg parasite, *Trichogramma*, and the convergent lady beetle have been used more extensively than any other species for periodic release, probably because the one is easily reared and the other can be collected in large numbers. There has been one successful case of control by the release of *Trichogramma* against cutworms attacking wheat in Russia, and one partially successful test of the same insect against the codling moth in that country. All of the other tests reported have failed or, at best, have given partial control. There have been no authenticated cases of successful control by the convergent lady beetle although collection and release of this species is still widely practiced. Egg parasites have, however, been used successfully against a caterpillar and pea bruchids in Russia, against the senn pest in Russia and Iran, and against a pentatomid attacking rice in Japan. Larval parasites have been used successfully against the greenhouse white fly, a woolly aphid on sugar cane, the California red scale and the black scale on citrus in California. Coccinellid predators have been successful against mealybugs on pears, citrus, gardenias, and chrysanthemums in the greenhouse, and the alfalfa weevil in Russia. Spider mite predators were highly successful against the cyclamen mite on strawberries in California. The secret of successful control by this method appears to be adequate investigation to determine that the enemy released is adapted to the host, the habitat and the weather, and does not disperse too widely. Proper timing of releases is also essential. Modern techniques of mass rearing and releases over much larger areas than in the past should increase the chances of successful control by this method.

Small-Plot Tests with Insect Predators to Control Aphids on Potatoes

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In cooperation with the Maine Agricultural Experiment Station at Presque Isle, in 1964 an experiment was conducted to determine whether the role of insect predators in controlling aphids on potatoes can be enhanced by supplementing their natural populations with several species in replicated, small-plot plantings. Supplementation consisted of sequential manual implantations during the period June 18 to July 23 of one level of abundance of eggs or of two levels of 1st-instar larvae of *Coccinella septempunctata* L., two levels of eggs of *Chrysopa* spp. (mostly *C. californica*, but possibly with some *C. majuscula*), or of applications of a foliar spray of a protein hydrolysate, which may increase egg deposition by chrysopids on the potato plants by attracting and nourishing the natural population of adults in the vicinity. In northeastern Maine this is a critical period in the population dynamics of the four species of aphids that infest potatoes--the buckthorn, green peach, potato, and foxglove aphids.

Statistically significant treatment differences occurred between July 23 and August 13, inclusive, both in numbers of apterous aphids and in percent of plants infested by the apterae. In general, implantations of the coccinellid larvae proved most effective against the total aphid population, while those of chrysopid eggs tended to be superior against the green peach aphid. In all instances percentages of aphids in plots receiving supplemental populations of predators were smaller than those in plots not treated, but there were few statistically significant differences among the predator treatments.

Depending upon treatment and species of aphid, the treatments delayed the time of aphid peak one to four weeks, and aphid control at the peak ranged from 0 to 89 percent. The delay in time of peak in most instances was but one to two weeks, and control of the total aphid population at the peak ranged from 0 to 54 percent. Similarly, all-season aphid control ranged from 0 to 85 percent, while that for total aphid infestation was 0 to 56 percent. By species, poorest control was against the potato aphid and best against the green peach aphid. With the technique employed in the weekly samplings, only questionable differences were found in populations of predators to result from the supplemental treatments of predators.

Mass Propagation of Pea Aphid Parasites

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We are attempting to produce hymenopterous parasites of the pea aphid on an economic basis which will allow inundative releases upon thousands of acres of crops. All previous work had as its goal the colonization and establishment of native or imported parasites. Where large scale releases were made, the insects were usually not reared but collected "en masse" from fields where they occurred in large numbers and transported to the release sites.

In our initial efforts, we tried adapting commonly used aphid-parasite rearing techniques to mass production use. It was soon apparent that too much time, space, equipment, and personnel were needed even if these methods could be adapted to our needs. Also, a number of unforeseen problems appeared. Vagaries in host plant and aphid development resulting from such factors as photoperiod, temperature, and relative humidity interfered greatly with the production program. This, coupled with behavioral problems of the parasites and aphids, clearly demonstrated that a new approach was needed.

Our prime need was a continuous supply of millions of aphids. Alfalfa, first used as an aphid food supply proved unsatisfactory for rapid aphid increase. Currently, we are developing techniques using sprouted pea seeds grown in flats containing vermiculite and irrigated with a nutrient solution. The flats of peas will be held in movable racks for the entire growth and aphid production period. Artificial lighting only will be used to eliminate photoperiodic problems and to insure uniform plant growth and condition. The pea production can be readily automated and it should be possible to handle the aphids volumetrically with vacuum collection and handling equipment as has been done on alfalfa.

Parasites will be produced in newly designed portable plastic cages now in use. The cages placed in the field over alfalfa of suitable condition are stocked with aphids and then parasites and left closed until parasite development is complete. During the growing season, the parasite infested hay is cut or the parasites themselves captured and transported to the release site. The cages are then moved to other locations and restocked. For release during inclement weather in the spring, cages placed over alfalfa in the release areas act as "hot caps" and provide early growth of suitable aphid host plants for parasite production. The emerging parasites are permitted to escape from the rearing cage into the surrounding field when normal field aphid populations warrant.

Possible storage techniques permitting the use of "off season" production are also being investigated.

[illegible]

Potential of the Citrus Red Mite Virus for Population Suppression

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A 2-year field evaluation program was conducted from 1962-64 to determine the practical value of a noninclusion virus disease for biological control of the citrus red mite. Infection was transmitted to field populations by spray applications of virus suspensions and by introduction of laboratory-inoculated mites onto infested citrus foliage.

The occurrence of epizootics was established for the first time and population reductions were correlated with treatment. Populations remained at low levels for more than a year when treatments were applied at 6-week intervals. Differences between methods of treatment or between treated and untreated plots were not established, apparently because of insufficient plot separation. Interplot movement of diseased mites was suspected of masking possible plot differences.

In January 1965, a natural epizootic of the citrus red mite virus was found in a lemon grove maintained under a biological control program. Continuous weekly surveys have been made to determine fluctuations in mite population and incidence of disease. Over a 13-week period mite populations, including the eggs and motile stages, have diminished from a mean of 109 to a mean of 16 per leaf; motile forms have diminished from a mean of 41 to 5 per leaf. Populations occurring after mid-March have been below economic levels.

Incidence of disease has ranged from a high of 67% to a low of 32% in dead mites, and from a high of 30% to a low of 2% in live mites sampled at random. The overall mean incidence of disease in dead and live mites during the study period has been 31%. Evidence thus far indicates that fluctuations in incidence of disease, especially in the live mites, is positively correlated with fluctuations in the air temperature.

Field experiments similar to those conducted earlier, except on a larger scale and with much wider interplot separation, will be initiated soon. Treatments will be maintained on an 8-week schedule, which will require production of approximately 250,000 to 500,000 diseased mites per week. The laboratory rearing schedule has been programmed to meet this capacity.

Boll Weevil Protozoa

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The protozoons, Mattesia grandis and Nosema sp., may affect a population by mortality of the adult, reduced oviposition rates, and transmission by infected females to their progeny. The expected effectiveness of each pathogen for each area was presented. Population suppression of the boll weevil by use of the pathogens would be best utilized in a program aimed at generation control and the multiple-factor suppression technique should be most effective.

Mass production costs of the pathogens were presented. Current methods employ the boll weevil as a rearing medium. Production cost estimates were made from current programs in which the majority of the cost arises from labor and should be subject to great reduction by employment of labor-saving methods. The current estimated rate of application resulted in an estimated cost of production of $54.00/A for M. grandis and $0.80/A for the Nosema sp.

Field tests conducted to date have produced infection of 60-70% of a population in small cage tests. A formulation of the feeding stimulant from cotton plants and the spores were used to induce adult weevil ingestion of spores.

The optimum point in boll weevil populations for employment of diseases along with other methods of population suppression were discussed. The overwintered and F_1 spring generation, as well as the late fall population attempting to enter diapause in preparation for overwintering, were considered more susceptible to this technique than the mid-season reproductive phase of the population.

Parasite of the Wax Moth

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Preliminary laboratory studies show that *Dibrachys cavus* (Walker) (Hymenoptera, Ptermalidae) is an effective parasite on the wax moth, *Galleria mellonella* L. (Lepidoptera, Galleriidae). Mass rearing media defined by Dutky for *G. mellonella* was used to obtain large numbers of mature wax moth larvae for the parasitism studies. Cultures of 500 wax moth larvae were divided into lots of 100 larvae each, and these were subjected to parasitism by varying numbers of *D. cavus* females.

Numbers of parasites reared per host per female showed the number of parasites necessary to effectively reduce wax moth populations. Ten female parasites per 100 wax moth larvae averaged 36 parasites reared per host larvae with all but two wax moth larvae parasitized. This was an average of 356 offspring from each female parasite. The combined data of six experiments showed the average number of parasites produced per host larva as 29. The average number of offspring produced per female parasite was 59.

Mass rearing techniques for the parasite were established on cultures of 500 wax moth larvae.

Crop Rotation and Other Cultural Practices for Corn Borer Control

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A highly publicized method of corn borer control is the destruction of corn stalks and other refuse in which borers overwinter. Although helpful, these practices are recommended to the extent that they fit into the general farming operation and can be accomplished without loss of time and money.

Survival studies in Boone County, Iowa, show that up to 90%, and an average of 78.2% of the borers present in the fields before harvest, are lost by the time the first brood starts to emerge the following season. This figure agrees with the 77% reported by Bigger in Illinois in 1953. Delayed planting reduces infestation but results in the loss of yield and possible loss from frost, and it is generally ignored as a control measure.

Crop rotation systems have an important influence on corn borer populations. The area most heavily infested by the borer in the North Central area coincides to a marked degree with the area that practices a corn-corn-oats-meadow rotation. The elimination of oats from the rotation would probably have considerable influence on borer populations in Iowa. A move in this direction is developing, for now about 25% of the corn is grown continuously on the same field without apparent loss in yield.

The introduction of corn combines is complicating the corn borer problem. The use of combines and driers has enabled farmers to use longer maturing and heavier yielding varieties. This is making the crop susceptible to the attack by both broods, and there are indications that it may be responsible for some population increases.

Another cultural practice that is developing is the shift to 30-inch rows from 40-inch rows. This cultural practice may create an environment which is more satisfactory for borer survival and development and may result in increased damage per borer per plant. This planting procedure is new and studies are now underway.

The most effective cultural practice is the use of corn that is resistant to corn borer attack. Corn inbreds are available that are almost 100% immune to borer damage. As more and more of these are introduced into commercial lines, the greater will be the impact on borer populations. For example, as high as 75% of all the hybrids planted in Ohio contain from 1 to 3 resistant inbreds. Corn borer populations and damage in Ohio is at a low level and the widespread use of resistant inbreds has undoubtedly contributed to this population decline. The use of resistant varieties appears to offer the best prospect for the biological control of this pest if the insect does not become adapted to its resistant host.

Role of Resistant Varieties in Suppression of Hessian Fly Populations

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Seventeen Hessian fly resistant wheat varieties are now suppressing fly populations in 33 States on approximately $8\frac{1}{2}$ million acres. This is an annual increase in wheat acreage planted to resistant varieties of approximately 2 million acres per year for the last three years. These varieties contain one or more of the Dawson, Kawvale, Marquillo, W38, or PI 94587 genes for resistance.

Suppression of Hessian fly populations in California, Kansas, and Indiana, exemplify the control given by resistant varieties. In California, due to almost a complete eradication of the Hessian fly from the planting of Poso 42 and Big Club 43, the insect resistance breeding program was discontinued since field populations could not be found to conduct further research. In northeastern Kansas the widespread use of Pawnee and Ponca on 60-72% of the wheat acreage suppressed the Hessian fly populations to a low level. With the preference for a disease resistant, susceptible Hessian fly variety, the percentage of wheat acreage planted to resistant varieties declined and immediately the fly populations increased. With the release of Ottawa wheat, the percentage of wheat acreage planted to Hessian fly resistant varieties climbed with a resulting decline in Hessian fly populations.

In Indiana with the release of Dual wheat in 1955, the Hessian fly populations in areas sown to resistant wheats were suppressed to a low level. With the release of Monon and Redcoat the acreages planted to W38 resistant wheats increased again, but a slight increase in fly populations also occurred due to the build-up of Race B in the area. In 1962 Knox 62 and Reed were released, making the total percentage of wheat acreage planted to Hessian fly resistant varieties to be approximately 80%. Knox 62 resistant to Races A and B, along with Redcoat, Reed, Monon, and Dual resistant to Race A, resulted in a suppression of Race B and Race A populations to almost zero in 1964.

Continued research is necessary to develop varieties resistant to all new races in the field in order to maintain the high level of control resistant wheat varieties are performing against the Hessian fly.

Range Management Practices in Relation to Grasshopper Population Suppression

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Several intermountain ranges in east-central and southeastern Arizona have frequently been plagued by grasshoppers. The overall grasshopper populations on these rangelands were decreased by large-scale chemical control operations in the late 40's and early 50's. In recent years much range research has been directed toward range reseeding and range improvement to grow more grass. Grasshoppers do not thrive on good grass areas, their preferred habitats being sparse grass usually dominated by low-growing weeds. Some management practices that have improved grazing land subareas and suppressed buildups of grasshoppers are: (1) Proper stocking of fenced pastures, (2) proper seasonal use of forage, (3) good livestock distribution through the development of water facilities, (4) deferred grazing, (5) control of certain insects other than grasshoppers, and (6) control of woody plants.

Observations from 1953 through 1964 show that differences in population levels are due mostly to differences in the grass cover of grazing land subareas.

Russian-Thistle Elimination for Beet Leafhopper Control

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Southern Idaho produces 85% of the bush-type snap bean seed grown in the United States, valued at $3 to $4 million annually. This crop is very susceptible to curly top, a virus disease transmitted by the beet leafhopper, and is affected to some degree every year by migrations of this insect from desert and abandoned spring breeding areas to the north, west, and northwest of the Magic Valley, Idaho, bean-growing areas. This spring brood is produced primarily on peppergrass, flixweed, and tumblemustard, growing on abandoned, overgrazed, and burned areas; and on green tansy-mustard, growing in the sagebrush areas. These plants are found on 2 to 3 million acres, but the stands vary from year to year. Early research workers felt that if the sequence of host plants could be broken, the leafhopper population could be reduced to one of unimportance. The most logical approach is to eliminate Russian-thistle, the most important summer host plant, since the acreage of 200,000 to 300,000 is smaller than that of the spring host plants.

In 1957 the bean industry of southern Idaho suffered more than $1 million loss. The Idaho Bean Commission immediately looked for help and in 1958 was instrumental in having Congress appropriate $300,000, to be administered by the Bureau of Land Management, for initiating a program to control the beet leafhopper by seeding Russian-thistle areas to perennial grasses. To date, there have been approximately 180,000 acres seeded to crested wheatgrass at an average cost of $5.50 per acre. Of course, there have been some failures and problems encountered, but Russian-thistle and the beet leafhopper have been eliminated from much of the area. At present the acreage of Russian-thistle has been reduced to such a low level that the leafhopper has not been a serious problem in our area for several years.

In addition to the seeding program, restricted grazing and climatic conditions have helped in reducing the acreage of Russian-thistle. Also, deep well drilling and development of pumping projects have made water available for irrigation and cultivation, which has replaced thousands of acres of Russian-thistle.

Host Elimination for Area Control of the Green Peach Aphid in Washington

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Three years ago we began some ecological studies of the vectors of beet western yellows and beet yellows virus diseases of sugarbeets in Washington. The purpose of these studies was to determine the vectors involved, the alternate host plants of the viruses, the overwintering sources of the vectors and viruses, and also the possibility of eliminating or greatly reducing the vectors and viruses during the overwintering period.

The green peach aphid is by far the most important vector of the "yellows" viruses in the Pacific Northwest. In this area they overwinter mainly in the egg stage on peach trees, but a small number overwinter in the summer-form in protected situations.

The beet yellows virus overwinters mainly in the sugarbeet in the Northwest, whereas beet western yellows has 30 or more alternate host plants, many of which are perennials and fall-sprouted annual plants.

We soon found that sugarbeet fields located near peach orchards supported high populations of green peach aphids during the summer as compared to fields that were remote from the orchards but near drain ditches where we found aphids overwintering in the summer-form. Conversely, beet fields located near the drain ditches developed a much higher incidence of "yellows" during the summer.

The following tabulation shows the relationship between average green peach aphid populations in sugarbeet fields close to drain ditches and peach orchards, and fields remote from either of these situations in 1963 and 1964:

	In fields near:		
Period ending	Drain ditches	Peach orchards	Open land
May 15	1 1/	0	0
June 1	3	10	T
15	4	24	T
July 1	10	264	8
15	50	2,962	45
Aug. 1	115	3,518	115
15	55	759	48
Sept. 1	3	193	5
Average	30	966	28

1/ Number per 100 leaves.

In the spring we found that aphids appeared somewhat earlier but in smaller numbers in beet fields near the drain ditches than in beet fields near peach orchards. The development of a high incidence of virus in fields near the drain ditches indicated that the small number of winged, summer-form aphids moving from overwintering on weed hosts in the drain ditches were highly infective. They infected the beet plants when small and most susceptible to infection. Aphids coming from peach trees where they have hatched from eggs are non-infective and must acquire the virus from some overwintering host plant before they can infect beet plants.

To determine if the elimination of the overwintering aphid population and the virus-carrying alternate host plants in the drain ditches would prevent infection in nearby beet fields, a plan was developed to destroy the aphids and host plants in a 25-square mile experimental area. This area on the Yakima Indian Reservation contained about 30 miles of drain ditches. The weeds were destroyed during the winter of 1964-65 by burning with truck-mounted propane gas burners. In addition, all peach trees near farm houses within the experimental area were sprayed to prevent the movement of aphids to beet fields.

We also plan to survey beet fields in the area during the spring and summer for aphids on beet and infected beet plants. This information will be compared with data in a similar area northeast of Sunnyside, Washington, where no ditch burning was done.

Cultural and Mechanical Methods as Applied to Suppression of Insect Populations
Host Plant Destruction for Pink Bollworm and Boll Weevil Control

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The pink bollworm, Pectinophora gossypiella (Saunders), is especially vulnerable to cultural and mechanical methods applied against potential overwintering populations. Many diapause larvae are removed from the field with the harvested cotton and are killed in the gin and oil mill operations. Those remaining are subject to a high mechanical kill by stalk shredding and a high mortality from deep plowunder at the proper time. Some winter survivors pupate early and may emerge as adults that die before squares are available for their propagation; thus, the planting date can be regulated to increase such suicidal moth emergence. The boll weevil, Anthonomus grandis Boheman, is generally less vulnerable to cultural practices. Diapause adult weevils usually leave the field to seek hibernation quarters, but early fall stalk destruction reduces winter survival.

The program practiced in the lower Rio Grande Valley of Texas and Mexico is presented as an outstanding example of cultural control of these insects. Cotton plants are seldom killed by freezes in this area. If not plowed out, they usually fruit throughout the winter, thus permitting continuous insect breeding. The program requires that cotton be planted February 1 to March 31 and the stalks destroyed by August 31. Stubs and volunteer plants must be plowed under before they produce squares. The program also applies to okra, the only other cultivated pink bollworm host in the area. Wild hosts are not a factor in controlling either of these insects. Early termination of insect breeding reduces seasonal buildup and the proportions in diapause at stalk destruction date.

The compulsory program, inaugurated in the fall of 1945 for suppressing pink bollworm spread, has proved very effective against both the boll weevil and pink bollworm. Records of boll weevil infestation of squares were made in June in three counties from 1944 through 1950. In 1944 and 1945, before the program started, the infestation averaged 38.5%. In 1946-50, following inauguration of the program, the infestation averaged 10.5%.

Records suitable for comparing pink bollworm infestations before and after the program started are not available; however, experiments have indicated the effectiveness of the program. The fall larval population is reduced about 80% in shredding with a flail-type shredder, or 50% with a horizontal-rotating type. Early fall, deep plowunder increases winter mortality over that for later plowing. Field cage experiments simulating stalk destruction on about August 15, September 15, and October 15 with infested bolls exposed on the soil surface and buried only 2 inches showed that survival to infest the next crop was 55 times greater for September and 400 times greater for October than for August installations.

Stalk Cutting Experiment for Suppression of Tobacco Hornworm Population

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At Florence, S. C., a large area experiment was conducted to determine if stalk destruction soon after tobacco harvest would give a reduction in the number of tobacco hornworms, Protoparce sexta (Johannson) and tobacco budworm, Heliothis virescens (Fabricius).

A circular area with a diameter of 12 miles was selected before the tobacco harvest had been completed in 1963. Each farmer in the area was contacted and asked to cut his stalks. A second circular area comparable in size was selected outside the cutting area. Farmers were not contacted to cut stalks. Approximately 87% of the stalks were cut in the stalk cutting area and only 73% cut outside the area.

Forty-three $\frac{1}{4}$ acre plots of tobacco were grown by cooperating growers during the 1964 growing season. The experimental plots were located some distance from the grower's tobacco field, and the plots were not treated with any pesticides.

Twelve untreated fields were inside stalk cutting area, four around the edge, and the other twenty-seven on four legs extending out from the circle edge.

It is considered important to know when the peak of egg abundance as well as larval abundance occurs. With this known, it might be possible to destroy the tobacco stalks when the lowest peaks occur and thereby prevent the last brood passing the winter. Peaks in egg abundance occurred on July 20 and August 24. Very small larvae peaked on July 27 and August 24.

There were 38 fields that were in the 16.2 miles distance from the center of the circle. We studied the relationship of eggs, very small larvae, very small larvae and eggs, and the large, medium, small, very small larvae to distance from center. It was not possible to show that there was a significant relationship between these populations and the distance from the center of the stalk cutting area. One reason for not being able to show a definite relationship was the enormous variation in the populations between fields. By taking the fields within the stalk cutting circle or by adding a few fields on the edge of the circle, it was possible to show that the hornworm population increased as the distance increased from the center of the stalk cutting circle.

Relationship between the hornworm egg and larval counts and the damage done by hornworms: These studies were based on all 43 fields in the test. All of the correlations were highly significant, thus indicating that the sampling technique was good for determining the hornworm population and damage caused by hornworm feeding.

Stalk destruction inside and outside the stalk cutting circle in fall of 1964: Inside the stalk cutting area 94.2% of the stalks were cut, whereas only 70.3% were cut on the outside area.

Genetic Approaches Other Than Sterile Insects In Population Suppression

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The disparity between our knowledge of genetic mechanisms in insects and our utilization of genetic knowledge in applied entomology is rather surprising. Sooner or later the genetical arsenal must be tapped as a source of entomological weapons. In the time allotted, I can only discuss a few of the various possibilities for insect control through genetic manipulations (see Table 1).

Table 1. - Possibilities for genetic control of insects

1. Conditional lethals
2. Unisexual lethals
3. Hybrid sterility
4. Sex ratio alteration
   a. Genetic basis
   b. Infectious basis
5. Cytoplasmic incompatibility
6. Meiotic drive
7. Other
   a. Population replacement
   b. Gene replacement

Conditional Lethals:

Some mutations are not expressed to the same degree in all environments - for example, at different temperatures or under laboratory as compared to field conditions. When the lethal effect of a mutation is not manifested under all environmental conditions, these mutations are called "conditional lethals" because their lethal effect is dependent upon the environment - for example, mutations requiring nutritional additives to the diet (which the insect cannot synthesize), inability to diapause, inability to fly, etc. Seasonal lethals and density dependent lethal factors seem particularly promising.

Such strains of insects could be reared successfully in the laboratory but carry genes lethal to their descendants living under field conditions. If such strains are vigorous and competitive with those of the native population, the frequency of progeny bearing the conditionally lethal genes would increase. If progeny failed to survive or reproduce due to genetic deficiencies, population decline and perhaps extinction would ensue.

Any attempt to introduce genes into a field population should be timed to take advantage of the natural fluctuation in population density.

Unisexual Lethal Mutations or Sex-Limited Factors:

Another prospect is the use of lethal mutations that have a unisexual manifestation. Such genes have no effect on one sex, but are partially or fully dominant in the other. Since one sex is unaffected by the mutation, propagation of the gene in the wild would be expected, while the number of progeny of the opposite sex would be depleted.

In *Drosophila*, there are many genes which result in progeny that are all or predominately of one sex. For an example, the mutant *daughterless* is an autosomal recessive factor. When homozygous females are mated to *any* male, they produce normal sons but no daughters.

Some heterotic factors are carried in populations as heterozygotes even though they are disadvantageous as homozygotes. In *Drosophila melanogaster*, there is a *recessive lethal* gene, l(2)55i, which increases fecundity of heterozygous females so that they produce 30% more eggs than wild-type.

A. B. Burdick of Purdue University designed a mechanism for control of *Drosophila* using *l*(2)55i plus daughterless. These two genes are closely linked on the second chromosome. Burdick combined the two in a single stock and released it near a bottling plant in Wakayama, Japan, - an area heavily infested with *Drosophila*. While the experiment could not be followed closely, one year after release fruit flies were rare in the area but abundant elsewhere. In samples collected 12 months after release, 35 of 75 flies carried the lethal-daughterless chromosome. It is not unreasonable to suspect that this mechanism depressed the population in the area.

Hybrid Sterility:

It is well known that crosses involving two different species or races, particularly in mosquitoes, result in the production of some fertile females and sterile males in the F_1 generation. With some crosses, the females in the F_1 have normally developed ovaries and all the males are without spermatozoa. The production and release of sterile hybrids seems a most likely possibility for the control of some insects. This approach has been seriously considered for the control of tsetse flies and gypsy moths.

Hybrid sterility might have some bonus effects. For example, in a species where the adults (or the males) do not constitute a hazard to health, comfort or food supply, the release of males from Race B into an area solely occupied by Race A would lead to the production of hybrids in the field. The efficiency of this method could be increased by prior treatment of the area with an insecticide to lower the density of Race A. Since the females seldom go unmated, the F_1 population would then be no greater than it would have been without the release of Race B males.

The size of the F_2 population would be greatly decreased due to matings between sterile hybrids or between sterile hybrids and the remaining fertile insects of Race A.

Factors Altering the Sex-Ratio:

Another interesting possibility entails the detection and use of genetic factors which alter the sex ratio of the offspring and yield progeny predominantly of one sex. This condition seems to operate in at least two different ways in insects. One has been called male-producing factor (MP) in mosquitoes and the other is sex-ratio (SR) factor in fruit flies.

The following facts are known about this male-producing (MP) factor in mosquitoes:

1. Present in many populations at different frequencies.

2. Not due to differential mortality, at least at post-gametic stages.

3. Due to an inherited factor.

4. Transmitted only by males; expressed only in males.

5. Not closely linked to the locus for sex determination.

6. Can be carried without being expressed; expression occurs on outcross (this is how the stock is maintained).

The sex-ratio factors found in *Drosophila* species are of two types: (1) chromosomal and (2) infectious.

The chromosomal type of sex-ratio factor in *Drosophila pseudoobscura* occurs in strains in which the X chromosome has a recognizable chromosome inversion. In the course of meiosis in males an extra duplication occurs while the Y chromosome is eliminated. As a result, all sperm are X-bearing and such males produce only daughters irrespective of the females with which they mate.

A more common sex-ratio factor in *Drosophila* has been known for many years although the details have only recently been elucidated. For many years it was known that certain strains produced progeny in which males were almost totally lacking. Research work on these strains has produced the following picture:

1. The SR condition is maternally transmitted via the egg cytoplasm -- only to daughters.

2. It causes death of males in the zygotic stage; i.e., after fertilization.

3. The killing effect of the SR agent on the egg is due to the single X-chromosome condition of the male zygote. The condition is not lethal to eggs which are XX.

4. The lethality to male eggs is temperature sensitive -- the lack of males is a consequence of lethality in the egg stage when the eggs develop at 21° C. or below.

5. The sex-ratio agent can be transmitted from strain to strain in *Drosophila* by injection *or* ingestion.

6. When transferred by injection into the abdomens of young virgin females of normal strains, they produce only daughters following an incubation period of 12-14 days. In this manner new SR strains are obtained.

7. It has been transferred from *Drosophila* to houseflies (Poulson and Sakaguchi 1961). The sex-ratio agent multiplied in the housefly, but was not transmitted to the progeny.

8. Strains which have SR are characterized by the presence of some spirochetes in the hemolymph. Transfer of SR factors from one strain to another is usually accompanied by the multiplication of the spirochetes in the hemolymph of the latter.

This is truly genetic control because various insect genotypes differ in their sensitivity to the spirochetes.

Cytoplasmic Incompatibility:

In some species complexes of mosquitoes, cytoplasmic agents cause incompatibility between populations. In *Culex pipiens* there are at least 15 different crossing types. All of them mate without barrier, but some crosses are fertile both ways, some are fertile only one way and some are sterile both ways. The sterility is due to a cytoplasmic factor transmitted through the egg which kills the incompatible sperm after entry into the egg and before karyogamy. In this manner it is similar to the SR factor in *Drosophila*, but the nature of this factor if unknown. The factor is definitely not located on any of the chromosomes but rather the basis for this incompatibility is extranuclear.

If found in other groups, control could be effected by mass rearing and release of males of one crossing type, separation of the sexes in the pupal stage and release of these males into an area populated by an incompatible crossing type. The result is similar to the sterile-male technique but circumvents the incapacitating effects of radiation. These agents have also been found in *Drosophila*, *Mormoniella*, and a species of *Chironomid*.

Meiotic Drive:

The phenomenon of meiotic drive is related to all other forms of genetic control in the way that a synergist speeds up a chemical reaction. Possibilities for practical use of meiotic drive in insect control cannot be ignored.

In classical Mendelian genetics, one learns that in a heterzygous insect the gametes are produced in a 1:1 ratio. In an increasing number of cases, there is evidence of preferential segregation favoring one kind of gamete at the expense of the other. Thus, a locus or a chromosome which exhibits meiotic drive has an advantage because it is present disproportionately often in the gametes contributing to each generation. Such a factor will tend to increase in a population. This provides a mechanism whereby the chromosomes (or genes) of a few individuals can sweep through a population even though the fitness of the population is reduced. Meiotic drive is probably a widespread phenomenon. Examples are known from plants and animals, as well as from a variety of insects.

Consider the synthesis and release of a meiotic-drive chromosome containing a gene for female sterility. As this chromosome sweeps through a population, the homozygous females would be useless for further propagation but the males would still be produced in disproportionate numbers. Eventually, every female would become sterile. A similar mechanism could be used to spread seasonal or conditional lethals or other unfavorable genes.

The two other possibilities which we can hurriedly note in passing are:

1. Population replacement. -- Replacement of pests by innocuous forms which occupy similar ecological niches.

2. Gene replacement. -- Since ability to harbor disease organisms is dependent upon the genotype of species, it might be possible to replace the populations with insects genetically unable to harbor the organisms. Thus, although the size population remains stationary, the incidence of disease could be wiped out.

Screw-Worm Eradication Programs in the Southeast and Southwest

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The success of the program to eradicate screw-worms from the southeastern part of the United States is well known. Screw-worm flies were reared on whale meat, irradiated, and released from light aircraft. Most of the releases were confined to invariable grid patterns with a uniform release rate of sterile males per square mile.

The program to suppress screw-worm populations in the Southwest was begun in the spring of 1962. The original concept of the scope of this program included the eradication of screw-worms from Texas and New Mexico, the establishment of a quarantine line in Arizona, and the maintenance of a barrier zone of sterile flies 50 miles south of the Mexican border. It was soon apparent that the release rates used in Florida were inadequate for parts of Texas. Release rates in areas with large populations of sheep and goats had to be increased from 200 to 1,000 sterile males per square mile.

In the spring of 1963, screw-worms spread rapidly through southern Texas and extended 490 miles north of the usual overwintering line before the end of April. Long-range dispersal of gravid female flies was indicated, and releases of sterile males were shifted deeper into screw-worm overwintering areas in northern Mexico. At the same time, a system for releasing flies over individual cases was instituted. Map coordinates were obtained on each case, and crosses were made with lime to aid pilots in locating the area where the cases occurred. In the more arid regions releases of sterile flies were concentrated along water courses. Ecological and case-incidence surveys were begun in the five northern States of Mexico up to a depth of 200 miles. Available information on climate, local weather, and livestock populations was compared with case-incidence data to determine where and when sterile flies were to be released. Swath widths were increased up to four miles in some instances to cope with the increased area of coverage. The efficacy of these changes in techniques is indicated by a decrease in reported Texas screw-worm cases from a total of 4,916 in 1963 to 223 in 1964. Sixteen cases have been reported from Texas since January 1, 1965, along with one from Arizona. These cases are being treated on an individual basis, and with this exception all sterile fly releases are now being made in the Mexican States of Tamaulipas, Nuevo Leon, Coahuila, Chihuahua, Sonora, and Veracruz.

Increased efficiencies are also being realized in the rearing of flies. The media costs when whale meat was used in Florida amounted to $210 per million pupae. The substitution of nutria or lung reduced the cost to $117 per million. Flies are now being reared on a fluid mixture of fish meal, dried milk, dried blood, and water at a cost of $58 per million.

Sterile Male Release Method for Boll Weevil Suppression

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In Baldwin County, Alabama, 136 acres of cotton in 24 fields were treated during the fall of 1963. Eight applications of methyl parathion reduced the potential overwintered population to very low levels. Each week for 5 weeks prior to a killing frost or stalk destruction populations were estimated at approximately 30 adult weevils per acre. Observations were made in the spring of 1964 in limited numbers of woods trash samples, on an extensive sample of seedling cotton and on squaring, potted trap plants in the treated zone and in an adjacent untreated buffer zone. No weevils were found in the treated zone, but weevil feeding was observed on the trap plants. Weevils were easily found by all sampling methods in the untreated buffer zone.

In the 1963 treated zone nine fields, containing 16 acres, were subjected to 11 weekly releases of sterile males in 1964. The remaining 15 fields, containing 120 acres, were subjected to an intensive insecticide program. The 115 acres in the 1963 untreated buffer zone were treated during 1964 to minimize the possibility of migrants flying into the experimental area.

Population estimates obtained during the 1964 season show that 67% of the eggs laid in the sterile male release fields were inviable. In the buffer zone fields only 4% of the eggs were inviable. In addition, 62% of the oviposition punctured squares in the sterile male release fields contained eggs, larvae, pupae or adults while 90% of such squares in the buffer zone contained a weevil form. Terminal data from shed fruit, fruit still on the plant and woods trash samples, showed from 156 to 1,258 boll weevil forms per acre in the buffer, 11 to 581 in the chemical control zone and 0 to 49 in the sterile male release fields.

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Sterile Insect Release Method for Melon, Oriental, and Mediterranean Fruit Flies

L. F. Steiner, Entomologist
Fruit and Vegetable Insects Research Branch
Honolulu, Hawaii

Medfly infestations were suppressed to a level 90% below normal throughout the last 6 months of a 12-square mile test in Hawaii that required 18 million flies and demonstrated usefulness of the method.

The first oriental fruit fly experiment on Rota, M.I., used 560 million flies in a 22-month period. Unexpectedly large and mobile wild populations that were 40 times as large in September as May, plus unanticipated high losses of 80% in aerial and ground cage sterile fly releases, combined to make overflooding impossible. A release rate of 32 million per week instead of 8 would have been required in the lowest population month when we attained our maximum 5:1 overflooding. A year later on Guam (210 sq. mi.) survey traps indicated that the adverse effects of two typhoons on oriental fruit fly host recovery had made survival so difficult that most breeding areas had become restricted to sheltered ravines across the northeast tip of the island. Releases there and farther down the island (but upwind of all known infestations) effected eradication with less than 25 million flies, proving the effectiveness of the method against this species when overflooding can be obtained. On Saipan, Tinian, and Aguigan (90 sq. mi.) 200 million sterile oriental fruit flies released over an 11-month period by Trust Territory personnel effected temporary eradication on Tinian and the periphery of Saipan, but could not suppress stubborn infestations in high, interior, almost inaccessible valleys from which a few flies kept reinfesting Tinian and downwind areas of Saipan. Overflooding was attained early but it was largely by sexually immature, thus ineffective, flies. After the first 5 weeks most of our flies began dying before they became sexually mature with losses of 80 to 95 percent. Many factors beyond our control (3800 miles away) contributed and have not been completely evaluated. Recent application of protein hydrolysate-sugar sprays to foliage at release sites significantly increased longevity and indicated that natural food sources on these islands probably could not support as high fly populations as needed to overflood. On Saipan and Tinian most of our flies died within 10 days, on Rota and Guam they lived up to 6 weeks. Two applications of methyl eugenol for male annihilation to all of Saipan and 4 to the heavily infested area checked a seasonal rise in infestation but made further releases useless. The two methods cannot be integrated without further research.

The successful melon fly eradication on Rota was accomplished with about 260 million flies. Losses of released flies averaged 65%. Overflooding of almost 90:1 was obtained in about 6 weeks. The species congregates at host sites at densities up to 15 times that in the non-host boondock areas. Pre-release protein hydrolysate bait sprays helped attain early overflooding. Larval infestations disappeared within 3 months late in 1962 and eggs (sterile) within 5 months. Stinging continued at a reduced level until releases stopped. Strong winds from Guam on 2 occasions and a typhoon on another brought wild melon flies to Rota in 1964. Each outbreak was eradicated by use of 200,000 to 400,000 sterile flies per week for 8-10 weeks released from cages placed upwind of the infestations.

Release of Sterile Flies to Prevent Establishment of the Mexican Fruit Fly in Northern Mexico and Southern California

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During 1964 chemosterilized males of the Mexican fruit fly, (Anastrepha ludens (Loew)) were released weekly in northern Baja California for control of native populations of this pest. Control the previous 10 years was obtained by the application of malathion-bait spray at intervals of 21 days.

Mature pupae, mass reared in the Mexico City laboratory of the Entomology Research Division, were treated by immersion in a 5% aqueous solution of tepa (Tris-(1-aziridinyl)-phosphine oxide). Sterilization resulted when the fly emerged and came in contact with the tepa residue on the exterior of the puparium.

A few days after emergence, flies were sexed and the females discarded. Sexually mature males were marked with colored lacquer applied with a nasal atomizer and packed in 1-liter ice cream cartons supplied with food and water.

Cartons of flies packed in cardboard boxes were shipped in the passenger compartment of a commercial airline flying non-stop to San Diego.

The PPC received the flies and released them in trees of dooryard plantings in northern Baja California. A total of 3,824,626 males were released at Tijuana, 231,000 males at Tecate and 688,380 males and females at Ensenada. By trapping, this same Division obtained indices of native fly populations; density and longevity of marked sterile flies was also determined.

Total capture of native flies in 1964 was less than in 1963. More flies were caught after midsummer 1964 than the previous year. This would be logical as native flies were not reduced by chemical control. However, the last native flies captured in 1964 were in October as compared to November in 1963.

Sterile males to native females always exceeded 1000:1, a ratio considered adequate to implement eradication. Large numbers of traps used within the release areas of Baja California captured over 2% of the marked sterile flies.

It was shown by trapping that half-life was 5-6 days and seldom were these flies taken more than 30-40 days after release. Sterile fly longevity was greatest in the Tecate area where tree harborage and water supply was quite adequate.

Flies of 3 ages, 3-4, 6-7, and 13-14 days old were released on 5 different occasions. Captures were greater for the younger ages but dispersal was the same for all 3 ages.

Control by sterile fly releases in 1964 appear to compare favorably with the malathion-bait spray program used the 10 previous years. As in those years, no host fruits grown in northern Baja California or in southern California have been found infested by the Mexican fruit fly.

Codling Moth Sterile Insect Release Method

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Yakima, Washington

The sterile-male method of codling moth control is being investigated at Yakima, Washington, and Summerland, British Columbia, Canada. Results of laboratory and field-cage tests using gamma irradiated moths look promising at both locations. The Canadians have achieved control of the codling moth in small isolated orchards by releasing male or male plus female insects sterilized with gamma irradiation, but we did not achieve codling moth control in Washington when we released moths treated with tepa.

We attribute our failure in Washington to: (1) Detrimental effects of tepa, (2) an underestimate of the overwintering population, (3) injury of moths by excessive handling.

A. 1965 Release Program

Moths will be treated with 15 µg. of tepa per moth in the 1965 release program. This rate will give us a high degree of sterility without the loss of male vigor that we suffered in 1964 when we treated moths with 40 µg.

Rather than estimate the populations and attempt to develop a release program accordingly as we did in 1964, we will pick apples in 1965 to adjust the codling moth population to the desired level. New methods have been developed to reduce the number of times the moths will be handled.

B. Practicability of the codling moth release program.

The major apple and pear growing areas of Washington are the Yakima, Wenatchee and Okanogan Valleys. There are about 65,000 acres for fruit in Washington, but the Okanogan Valley extends into Canada. These Valleys are bordered by a desert on the east and by the Cascade range on the west. This offers fair isolation although there are a few back-yard plantings throughout the State.

The codling moth population is now at an all-time low because of effective insecticidal control. A well managed orchard may have one larva per tree or per acre.

The codling moth is the key insect which prevents an integrated control program. We have no good biological control of the codling moth and the codling moth sprays cause a build-up in spider mites, our most serious pest of apples. If the codling moth, and therefore the codling moth sprays, were removed from the orchard, our mite population would return to the pre-DDT level and we would also be able to go into an integrated control program.

Gypsy Moth Chemosterilant Tests

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Preliminary screening tests in 1963 with apholate, metepa and tepa indicated that the latter two were effective as chemosterilants when used as residual films on adult male moths. Moths exposed for periods of 6 - 24 hours to tepa films of 5 mg./ft^2 showed 99.8% sterility in the resulting eggs. Metepa at 50 mg./ft^2 gave total sterility.

A small field test was conducted in 1964 with tepa sterilized moths. Fifty sterile marked males were released in each of 3 - 1 acre test plots. Concurrently, 50 normal unmarked males were released. One hundred baffle traps containing virgin females were placed in each plot. Out of 300 moths released, 84 were recaptured. Twenty four percent of the sterile males and 32% of the normal males found their way to the females. Mating took place in all instances. In all cases, the marked moths resulted in sterile egg masses. One lone larva hatched from a composite of the sterile eggs. In the case of eggs from the unmarked moths, an average hatch of 12% was obtained.

Sterilization and Genetic Method for Population Suppression - Pink Bollworm

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Male pink bollworms can be sterilized (S) by topical application on all parts of the body (15 µg of technical metepa/♂). In addition, exposure for 15 minutes to a residue of technical metepa (2516 µg/cm^2) S males. The S males were fully competitive with normal (N) males in mating with females at all ratios tested from 1:1 to 9:1 (S:N). With a constant male ratio, 4S:1N, and varied dosages, males sterilized with 15 µg to 25 µg of technical metepa were fully competitive with N males and exhibited some competitiveness when sterilized with 50 µg.

In field-caged experiments with a single release at a 9:1 (S:N ♂) ratio, males sterilized with 30 µg each did not reduce the population when compared with that in the untreated checks, but those sterilized with 15 µg reduced the number of F_1 larvae by 81%.

The female sterilizing dosage was 60 µg/ea. at 30 µg, 10% of the deposited eggs hatched. However, when the ratio of treated females to normal females was a constant 4:1, and the dosages varied, treated females were fully competitive with normal females from 30 to 60 µg.

Effects of Gamma Rays on the European Corn Borer

Earle S. Raun, Entomologist
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Walker and Brindley (1963) reported on their irradiation of pupae and adults of *Ostrinia nubilalis* (Hübner). They obtained sterility when 1-day-old adult moths were irradiated with 32,000 roentgens from X-rays. They found pupae were more susceptible to irradiation injury than adults and that sterility was more difficult to obtain at a level not morphologically damaging to the insect.

After finding that spermatogenesis begins in 3rd instar corn borer larvae, we began irradiation of larvae in the 3rd, 4th, and early 5th instar. A cobalt pile was used as the radiation source. Dosages ranged from 2,000 roentgens to 20,000 roentgens. Results of these tests show that:

1. Up to 5,000 r has little effect on pupation other than to delay it by 2 to 4 days.
2. Numbers of moths morphologically abnormal increase from larvae irradiated above 3,500 r.
3. Mating is normal up to 3,000 r. At 3,500 r males mate poorly, but females seem to mate normally.
4. Egg production is not adversely affected when irradiated males (up to 4,500 r) mate with non-irradiated females. Egg production by females irradiated at 3,500 r and above is reduced.
5. Hatchability is nearly eliminated when males have been irradiated with 2,500 r or more. Females produce viable eggs even when irradiated with 3,000 r, but hatchability is reduced at 3,500 r.

Additional tests have been run with larvae in diapause. Radiation levels used on these larvae have not exceeded 4,500 r. At this dosage and below there is no effect on pupation, emergence, apparent normalcy of moths, and mating. Egg production from females mated with irradiated males is normal but irradiated female egg production drops at 4,500 r.

Hatchability of eggs from these moths is unique and further tests are now being run. At 2,500 r essentially no hatch occurred from pairs in which either sex was irradiated. At 3,000 r no hatch occurred where the male of each pair was irradiated. Hatch of eggs from irradiated females was normal at 3,000 r. Hatch of eggs from irradiated moths was normal at 3,500 and 4,000 r but was reduced when males were irradiated with 4,500 r.

The possible explanation for the hatchability results is as follows: 2,500 and 3,000 r may produce a lethal mutation without otherwise injuring the sperm. At higher levels of irradiation, spermatocytes are completely knocked out and replaced by spermatocysts from uninjured spermatogonia.

References Cited

Walker, John R. and Tom A. Brindley. 1963. Effect of X-ray exposure on the European corn borer. J. Econ. Entomol. 56(4):522-525.

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Recent Trends in Chemosterilant Development

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The aziridinyl alkylating agents (e.g., tepa, apholate) are still the most versatile and least specific chemosterilants. Most of these compounds, however, have LD_{50} (mammals) $\sim$100 mg./kg. or less and some are known to be mutagenic in bacteria. Some are also known to affect reproductive organs in mammals at sublethal dosages. Aziridines are well suited for laboratory work and controlled orientation experiments; in the field they can be used only under conditions which preclude environmental contamination.

The trend in the last two years was toward the development of non-alkylating sterilants with mammalian $LD_{50} > 100$ mg./kg. Amide-type compounds exemplified by hempa and hemel and the triphenyltin compounds are outstanding examples of such sterilants. They are characterized by very high species specificity and at present there is no way of predicting whether a given compound active on one insect will have any activity on a different insect. This situation calls for intensification of screening on as many different insect species as possible.

Drosophila Control in Tomato Field Plots with Chemosterilants

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Studies were conducted at Beltsville, Md., on the control of *Drosophila melanogaster* Meigen in partially isolated quarter-acre tomato field plots in 1961 and 1962 by releasing adults sterilized with 1% apholate and in 1963 and 1964 by using baits containing 2% apholate.

In 1961, eggs laid by wild isolated females collected from the field plots revealed the release of sterilized adults had resulted in maximum reductions of 85% and 44% in adult progeny for Areas A and B, respectively, which occurred about 1 week after the last release. Eggs from wild isolated females in 1962 disclosed the releases had produced a maximum reduction of 50% in adult progeny with an average of about 40% from August 7 to October 2. Samples of the wild fly population taken from the plots with baited traps revealed the 1962 releases had given a maximum of 90% control of wild drosophila with an average of 80% control from August 22 to October 9.

In 1963, females isolated from plots treated with baited jars or hampers of ripe tomatoes sprayed with 2% of apholate (each 16/acre), revealed the treatments produced average adult progeny reductions of 54% and 35%, respectively, from August 27 to September 25. The apholate-baited jars and apholate-sprayed tomatoes gave maximum field control of 63% and 28%, respectively, of drosophila flies. Diazinon granules, 1 pound/acre application which was used as a standard for comparison, gave maximum control of 93%.

Investigations with apholate baits in 1964 on small plots (50 x 32 feet) separated by 50-foot strips of cultivated soil did not show any differences in control which was probably due to excessive interplot movement of drosophila flies.

House Fly Control on Some Caribbean Islands with Metepa, Apholate and Trichlorfon

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Metepa and apholate were applied in baits on two Caribbean islands to assess the effectiveness of the sterilant concept for the control of house flies.

Excellent control was achieved for almost 2 years on Grand Turk Island with metepa sugar baits applied in latrines. Sterility as evaluated by egg fertility progressively increased and house fly abundance correspondingly decreased within a one-year period.

The apholate bait, although applied in the same manner, was less effective in the Mayaguana Island test.

A comparative test with an insecticide bait was concurrently carried out on the island of San Salvador. Control acheived was good, but never that derived with metepa on Grand Turk Island.

Chemosterilants for the Melon Fly and the Mediterranean and Oriental Fruit Flies

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Honolulu, Hawaii

Candidate chemosterilant compounds have been under investigation at the Honolulu laboratory since 1959. The most promising that can effect partial or complete sterilization of tephritid fruit flies include tepa, metepa, apholate, and tretamine. This work has been under the immediate supervision of Mr. Irving Keiser. In ratio tests he has been unable to demonstrate that oriental fruit flies sterilized with tepa had any advantage over the same species when sterilized with 10,000 roentgens of gamma radiation.

Lately we have been concerned primarily with developing the best means of safely utilizing these materials in the field to sterilize the wild population rather than the release of flies sterilized with chemosterilants. This has value in fruit fly control because the sterilized female fruit flies do cause some stinging of fruit and the numbers required to overflood the population may cause as much sting injury during the period of an eradication program as formerly caused by the wild flies.

Mr. Keiser found that a high degree of sterility in wild Mediterranean fruit flies was induced by exposing the powerful male attractant, trimedlure, behind a screen guard on the lower surface of a composition board suspended horizontally. The area around the lure on which flies congregated was coated with tepa. The lower surface, protected from sun and rain, continued to permanently sterilize arriving male flies for a week before retreatment was necessary. We believe there may be some possibility for use of chemosterilants in combination with the powerful male lures. Tests with cue-lure and with methyl eugenol used in the same manner as the trimedlure have given excellent results. Bait stations could be placed behind screened areas through which the flies could enter and leave freely and yet create no hazards to birds or other wild life. If the male lures could be placed across the line of direction of prevailing winds in a long front that would blanket the area downwind with the lure, it should be possible to attract and sterilize all male flies within $\frac{1}{4}$ to $\frac{1}{2}$ mile, depending on species. Many of these flies would remain close enough to come back day after day, but others would be expected to drift on downwind into areas beyond the reach of the lure. The male flies all leave the lure at dusk and would not return until dawn. There is no flying after dark and many could escape influence of the lure after they became sterile and would not be trapped by it.

The Mediterranean fruit fly generally required higher concentrations of tepa, apholate, metepa, or tretamine to effect complete sterility in one or both sexes than the oriental fruit fly or melon fly regardless of the method of treatment. Tepa in drinking water at 0.1% concentration provided complete sterility of the three species when available the first 3 days after emergence. When protein hydrolysate containing 5% tepa was applied to guava foliage to which flies had access, complete suppression of the oriental fruit fly and melon fly egg hatch was obtained. A 10% concentration stopped egg deposition. Tepa in a 0.1% water solution usually stopped hatch of eggs from old fertile females of both species within 48 hours after ingestion and caused a rapid reduction in egg deposition. Most females that had demonstrated capability for producing fertile eggs completely stopped egg deposition within a week.

First Efficient Chemosterilants Against Screw-Worm Flies

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Male screw-worm flies, sexually sterilized by ENT-50,716, ENT-50,781, or gamma radiation, competed for mates about equally with normal males. Males sterilized by ENT-50,838 surpassed normal or radiosterilized males in mating competitiveness by a factor of at least four.

Chemosterilization of the European Corn Borer

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The chemosterilization of the European corn borer is still being investigated. However, a few general conclusions can be drawn from current investigations.

1. Due to the irregularity of adult feeding, it is not practical to sterilize the moths by oral treatment.

2. Gametogenesis begins in the 3rd instar of the larval stage. Mature sperm and eggs are present in the pupal stage and the moths mate the first night following eclosion. Therefore, when treating the adult insect, large doses of chemosterilant are required to sterilize the adults. Chemosterilants such as apholate, metepa, and tepa are too toxic to the moths and the moths are killed before complete sterilization.

3. Hempa is less toxic to the moths and it may be possible to achieve partial sterility without reducing the vigor of the moths.

4. It requires 2 to 4 times as much chemosterilant to sterilize the female moths vs. the male moths.

5. Hempa can be used to sterilize adults by treating partially developed larvae. When 5-day-old larvae were placed 24 hours on hempa treated diet, the resulting male moths were 90% sterile. The longevity and mating rate of the treated moths compared favorably with the untreated moths.

Need for Isolation for Basic and Applied Research To Investigate Total Population Concepts

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Isolation definitely is not required to successfully investigate any new concept intended for total population suppression. However, carefully controlled experiments are required and they must be designed to provide reliable information on the total effort and methods needed to accomplish suppression. Along with this is required a good knowledge of the insect's flight habits and the impact of adjacent populations on results when isolation is not feasible. Isolated pilot tests that go all the way to eradication may well be necessary to sell the concept to the taxpayer but not to test validity of the concept. I am sure of this because the three concepts for eradication of the oriental, melon, and Mediterranean fruit flies, that have been developed and successfully demonstrated on isolated populations, were originally evaluated and perfected under terrific population pressure from contiguous and even distant infestations. Few highly mobile insect species find it progressively easier to survive as their population thins out. Their mobility carries the few survivors farther apart and inability to find a mate as soon as sexual maturity is attained increases the probability of death without reproduction.

The protein hydrolysate-organic phosphate bait spray was found to attract and kill all flies present within and adjacent to properly sprayed areas within a few hours after application and to have good residual action. It was only necessary to insure applications at intervals throughout 1 generation that would prevent attainment of sexual maturity. The almost 100% control frequently obtained in Hawaii in the presence of moderate amounts of reinfestation demonstrated conclusively that the treatment could achieve eradication if applied to the total population. With lures available only a little extra on-the-job research was necessary to adapt both detection and control programs to the Florida 1956 Medfly eradication program and eradication was readily accomplished.

The sterile fly release method was virtually assured of success (although many almost insurmountable logistical problems were encountered) when laboratory ratio tests in Honolulu proved that multiple mating habits would be no deterrent. Suitable mass production methods were available. Methods of moving the pupae to the release sites without serious harm were also developed. Although the release rate for adequate overflooding was underestimated initially, the concept was sound.

The male annihilation concept depends on development of methods that would kill the males before any could reach sexual maturity. Since all males responded at some or at all times before sexual maturity, it was only left to determine the amount of lure that needed to be applied, the frequency of application, the method of dispersal, and the duration of the suppressive action after males disappeared to work out the procedures required. It was done in relatively small area tests of 3 to 6 square miles. It was, of course, obvious from the beginning that the poison had to outlast the lure. The lure had to be placed where the flies could reach it and where it wouldn't leach into soil and attract flies without killing them. Suppression of 70-100% for various periods in the preliminary tests proved the soundness of the concept before any total population tests were conducted.